Environmental Action Programme Support Project
Contract DHR-0039-C-00-5034-00
United States Agency for International Development

LAKE AND WATERSHED MANAGEMENT EVALUATION FOR LAKE ELCKIE, ELK, POLAND

Submitted to:
USAID/ENI/EEUD/ENR
and
OAR/POLAND

Submitted by:
Chemonics International Inc.

June 1997

Environmental Action Programme Support Project
Contract DHR-0039-C-00-5034-00
United States Agency for International Development

LAKE AND WATERSHED MANAGEMENT EVALUATION FOR LAKE ELCKIE, ELK, POLAND

Prepared by:
Ken Wagner, ENSR
through the
Institute for Sustainable Communities
Subcontractor to Chemonics International, Inc.

June 1997

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The USAID Environmental Action Programme Support (EAPS) project in northeastern Poland assisted the Town of Elk enhance its potential as an environmentally focused tourism area by improving the overall quality of Lake Elckie. The Lake Elckie project was conceived by the Local Environmental Action Programme in Poland and prepared by local authorities with assistance of the Vermont-based Institute for Sustainable Communities and the Warsaw-based Institute for Sustainable Development (see Annex C for the Environmental Action Protection Plan).This report presents recommendations for engineering and scientific solutions to improve lake and watershed management. The analyses were performed by Ken Wagner in association with the EAPS project.

A. The Problem

Over the last several years, Lake Elckie in the Mazurian district of northeastern Poland has received excessive loads of nutrients and other contaminants from inflows of sanitary sewage, urban runoff, and agricultural non-point discharges from the surrounding 967 km^2 watershed. This 382 ha lake is comprised of three distinct basins (the north, south, and west) with differing depths and hydrology. Each basin is connected within the lake, with the north basin draining into the south basin, which in turn drains into the west basin.

The biological, chemical, and physical properties of the three basins vary. The deep north and south basins are stratified into two distinct layers. This is the result of temperature and density differences between the top and the bottom. Stratification is only slight in the shallow west basin. Bottom waters in all three basins become anoxic during summer, causing bacteria to go anaerobic and producing hydrogen sulfide through the decay of organic material. Phosphorus through chemical reactions is also released from the sediments, causing internal phosphorus recycling which enhances the algal growth. The high quantity of nutrients results in a highly productive state, which causes blooms of bluegreen algae to plague the surface waters during the summer. The unbalanced ecological conditions and poor water quality of the lake have led to poor water clarity, increased health risks from recreational activities, and a suboptimal fish community.

B. Management Goals

The overall goals for Lake Elckie are to:

- Minimize risks to human health and aquatic ecology.
- Improve water clarity.
- Improve fishing opportunity.
- Enhance overall lake aesthetics.

Management efforts to date have greatly reduced pollutant loading to the lake, especially as a result of wastewater treatment upgrade and discharge relocation to a point downstream of the lake. Continued discharge of nutrients from the surrounding area (watershed loading) is still significant, but phosphorus being released from the sediment appears to be high enough to support observed algal blooms without consideration of watershed loading. While it is essential to continue reducing watershed loading of nutrients, it is also important to implement engineering solutions toward in-lake management.

C. In-Lake Management

The following actions are central to improving the lake:

- Increase the oxygen concentration of bottom waters.
- Reduce algal biomass.
- Decrease phosphorus recycling in the surface waters.

Aeration (which adds oxygen to the lake) appears to be the most appropriate in-lake method for accomplishing these actions. Aeration has the ability to increase oxygen levels and eliminate hydrogen sulfide production, but its effect on phosphorus levels and associated algal blooms can vary. The impact of aeration can be enhanced by adding phosphorus inactivators which have the tendency to bind the phosphorus, making it unavailable to the algae. Of the inactivators available, iron is the most appropriate choice for this lake. Aeration effects can also be increased in association with biological treatment facilitated by the placement of substrates in key areas of the lake. These substrates, essentially a biological treatment system, promote biological growth which also binds phosphorus.

D. Management Costs

An appropriate aeration/phosphorus inactivation system for the north basin of Lake Elckie costs from $115,000 to $230,000, depending upon the sophistication of the system. The less expensive system would include only one partial lift (non-destratifying) aerator with iron injection capability, while the more expensive system would include additional diffuser aeration systems placed in two areas and supported by iron injection. The more expensive system provides greater capacity and flexibility. It would be possible to begin with the less expensive system and expand to the larger system as needed, but the more expensive system is expected to provide better results more rapidly. Operational costs will range from $4,000 to $20,000 per year, but may decrease over time.

Until greater control of watershed inputs can be obtained, it may be possible to limit the effect of inputs from the Elk River and Lake Sunowo by aerating near the input points. Iron additions and/or the use of substrates which promote attached biological growths would enhance effectiveness. A pilot program to test this approach is recommended for the Lake Sunowo inflow, at an expected cost of $11,000 (iron addition) to $20,000 (substrates). While the capital cost of biological treatment substrates is greater than for iron addition, the long-term maintenance costs are lower, and the use of substrates is recommended in this pilot effort. Expansion upon success in input control could make restoration of the south and west basins possible through further in-lake aeration.

Management planning and implementation should be supported by monitoring, and a 15-month program is recommended at a cost of up to $18,000. Determining the constraints on the application and effectiveness of management actions is essential to future efforts at Lake Elckie and elsewhere in Poland. Technical assistance is available for the monitoring program, but the Town of Elk should develop a volunteer monitoring program to maximize information gained per dollar spent and foster local education about the lake.

E. Timing

Monitoring should begin immediately, with preparation of a bid package for aeration and phosphorus inactivation by October 1997 and installation and operation by May 1998. A more rapid process would allow operation of the aeration system over the winter, with expected improvement in the lake by spring. Results could be evaluated by October 1998. Funding is central to continuing the management program for Lake Elckie, and efforts should be initiated to find sponsors to share costs with the Town of Elk.

SECTION I
INTRODUCTION

The USAID Environmental Action Program Support (EAPS) project has been working with the Town of Elk in northeastern Poland to enhance its potential as an environmentally focused tourism area. Though Lake Elckie is viewed as critical in attracting tourism, it is in a degraded, polluted state. A plan for both watershed and in-lake improvements has been devised, and major watershed to improve sanitary sewage and storm water management are in progress (see Annex C Environmental Action Protection Plan). EAPS obtained technical assistance in further evaluating the plan as it moves into its next phase, further watershed management activities and in-lake efforts to reduce internal recycling of nutrients.

The problems of Lake Elckie are not unique. Most of Poland’s 9,000 lakes larger than 1 ha are believed to be eutrophic, with urban lakes tending to have the greatest deterioration (Kudelska 1992). An estimated 30 percent of all Mazurian lakes have problems similar to those of Lake Elckie, brought on by years of sanitary sewage inflow, agricultural runoff, and urban storm water (EAPS 1997). Effective watershed management techniques have not been applied in many cases due to the cost. In-lake methods, however, have been initiated in a number of lakes; most involve some form of aeration (Kudelska 1992). Since 1993, environmental funding programs, such as the Polish EcoFund or the Polish National Fund, have provided resources for more costly environmental management projects, including wastewater treatment facility construction and upgrade and establishment of parks and preserves (such as Biebrza National Park downstream of Lake Elckie) (EcoFund 1996).

What is unique about Lake Elckie is the environmental progress that has taken place since the 1980s. The Town of Elk has taken an active interest in environmental management and made a major commitment to improving wastewater collection and treatment. Under the guidance of EAPS, it recently established goals and outlined the next phase of environmental improvements. The town, taking its moniker “Elk—Ecological Town” to heart, is continuing its efforts to reverse past impacts. Lake restoration is a focal point.

A. Lake Management Objectives for Lake Elckie

A critical step is defining management goals and their relative priority. The management process should revolve around clearly stated goals for making the lake and its watershed safe for public use. Not all goals are completely compatible, and it is important to establish a priority order to facilitate both technical and economic assessments of options.

With substantial support from community leaders, the Town of Elk has established goals for the town in general and Lake Elckie in particular (LEAPS 1996). Our understanding of the lake management objectives is as follows:

- Reduce or eliminate any conditions that constitute a threat to human health or aquatic ecology.
- Improve water clarity to make the lake appealing for swimming and boating.
- Improve fishing opportunity and satisfaction.
- Improve overall aesthetics, including shoreline views, odors, and water color.

An additional objective, not clearly stated but certainly implied, is to periodically assess conditions and make management adjustments to respond to future threats to the lake.

Water clarity and fish production. The objectives of water clarity and fish production are not completely compatible. The clearest water will not support extensive fish production. However, while low water clarity and high fish production often correspond, it is possible to support both satisfactory contact recreation and a desirable fishery in the same lake, though the extreme for each may not be achieved. In Lake Elckie, which has three distinct basins, the potential for physical separation of conditions and uses enhances the potential for multiple uses with minimal user conflicts.

Setting priorities. The above objectives have not been clearly prioritized, and some detailed definition of each would be helpful to future management. It seems apparent that improved water clarity and aesthetics take precedence over improved fishing, although some improvement in both is possible and entirely compatible. Reduction of human health threats may be the top priority, but public perception of the lake is more likely to be tied to factors such as visual appearance and odors than to fecal coliform counts or concentrations of pollutants. Nevertheless, minimizing health threats is essential if the lake is to become safe for swimming.

Detailing objectives. It would be helpful to set a specific water clarity goal for Lake Elckie. Water clarity of >1.2 m is used as a measure of swimming safety in the United States, but most people prefer to see the bottom in the swimming area, necessitating a clarity of about 2 m during the summer for consistent satisfaction. Achieving clarity levels >3 m during summer may require additional large decreases in nutrient loading; while this would improve public perception of the lake, it might be economically infeasible and adversely impact fish production.

Defining the desired fish community would aid management efforts. For example, adding trout would undoubtedly be well received, but may require a major increase in the summer oxygen content of the lake's bottom waters. In another example, if increased pike density is desired, then an increase in submergent vegetation is required. It is assumed that a general increase in fish size and predator abundance is desired, but the exact nature of the community shift has not been stated.

All aspects of the management objectives need not be clearly defined now, but continued refinement of management objectives will help determine success and the priority of future actions. This may be especially critical where funding is limited and the improvement program is expected to take multiple years.

B. Conceptual Framework for Lake Management

To help all participants in the lake management effort grasp the lake's complicated natural system and evaluate the meaning of proposed actions, the analogy of the leaky boat has been put forth.

If we envision a lake as a boat, it has the potential to float and provide tremendous enjoyment as long as it does not fill with water and sink. Lakes tend to accumulate nutrients and become eutrophic or overly productive, while boats tend to become leaky. If the leaks are too great, the boat may sink. Leaks may be caused by a variety of factors, just as eutrophication of lakes can be related to a variety of nutrient sources.

If the leaks are small, they might be completely ignored for the duration of a trip, although eventually some management of the boat will become necessary. If the leaks are substantial, the boat will fill with water too rapidly and the occupant must decide whether to plug the leaks or bail out the boat, or both. Maintaining a boat by plugging leaks is much like managing a lake by controlling inputs from the watershed. It is certainly the most desirable approach, but is not always easy and can be costly. Choosing to bail out the boat is more like managing a lake by only in-lake methods, such as chemical treatment, plant harvesting, or aeration. It is a viable strategy when the leaks are small, and may be necessary after patching the leaks to keep the boat afloat.

In the case of Lake Elckie, the boat has some large leaks and has become full of water. The biggest leak (sanitary sewage pollution) is nearly plugged now, and we know where the next biggest leak (storm water inputs) is and have plans to fix it. It has not been clear whether or not the time has come to bail out the boat yet. Are the leaks still too large to make bailing worthwhile? Are there leaks we do not yet know about? We must determine the most cost-effective way to achieve our goal: keeping the boat or lake in usable condition. This report is intended to address these questions, along with providing some insights into the best ways to bail or plug leaks and to provide some preliminary cost estimates.

SECTION II
TECHNICAL BACKGROUND

A large number of short reports about Lake Elckie and its watershed are available, and most of this information has been summarized in the (see box below). However, there is no assessment of the lake over a continuous period of a year or more (known as a diagnostic/feasibility study), as is commonly performed when developing a lake and watershed management plan. Although no additional data have been generated by this investigation, existing data have been assimilated into a format to facilitate informed lake management evaluation.

A. Lake Features

A1. Physical Attributes

Lake Elckie covers 382.4 ha in the Mazurian Lakes District in northeastern Poland. It is the eighth deepest and 120th largest among Poland's 9,000 lakes and appears to be derived largely from glacial activity. The lake has three distinct portions, each with several sub-basins based on subsurface morphometry (Figure II-1, page 6). The north basin flows to the south basin, which flows to the west basin. Table II-1 summarizes individual basin features.

North basin. Bordered by urban land to the east and agricultural land to the west, this basin's eastern shoreline is largely structurally stabilized, while its western shore is naturally vegetated. The eastern shore is a long promenade that has been part of the landscape since at least the 1930s. The discharge from Lake Sunowo enters the north basin from the north, and 10 storm water drainage systems discharge from the east, although most of the systems are

Sources of Information on Lake Elckie

- Environmental Protection Action Plan by the LEAPS Project Committee, Elk, Poland, 1996.
- Implementation Plan of Environmental Protection Action Plan by LEAPS, Elk, Poland, 1997.
- Trophic and Water Quality Parameters, Lake Elckie, by the Polish Academy of Sciences, Institute of Ecology, Hydro Biological Station, Mikolajki, Poland, 1996.
- Offer and Design Concept for Lake Elckie Reclamation, by EkoTech, Warsaw, Poland, 1996.
- Data from the Polish Fishing Society, Gizycko, Poland, 1994.
- Data from the files of the Town of Elk, made available by Jaroslaw Wasilewski, LEAP
coordinator, extending back to 1930 but mostly from the 1990s.

Table II-1. Individual Basin Features

Parameter	North Basin	South Basin	West Basin	Entire Lake
Area (ha)	80.4	185.5	116.5	382.4
Mean depth (m)	9.7	24.2	4.1	15.0
Maximum depth (m)	24.0	58.2	11.7	58.2
Volume (cubic c)	7,779,000	44,885,000	4,756,000	57,420,000
Matalimnion depth (m)	5-8	5-8	5-8	5-8
Stratified area (%)	70	15	15	64
Stratified volume (%)	21.0	62.7	1.3	52.0

Figure II-1. Lake Elckie Bathymetry

small. There is one storm drainage discharge to the southwest. The north basin has two discernible sub-basins, one of 23 m depth and one of 24 m depth, and drains into the south basin under the bridge at its southeastern corner (Figure II-1). Although water level equilibration and wind may at times cause water to flow from the south basin to the north basin, this is not the normal flow route.

South basin. Bordered by largely urban and park land to the east and undeveloped woodland and field to the west, this basin is the subject of plans for possible future development away from the lake on the west side. Some of the eastern shoreline is artificially stabilized, but most is naturally vegetated. A tourism club at the mouth of the Elk River offers several types of boats to members. A large beach and swimming complex developed by the town in one eastern cove of this basin includes a section of the lake previously used for log storage for the lumber mill, and there is a lot of bark and wood debris still on the bottom. Discolored water and floating woody debris are localized problems in this area.

The Elk River enters at the northeast corner of the south basin, a culverted overflow from Lake Szyba enters in the southeastern cove, and there are eight storm water drainage discharges along the east side and two more on the south side. The south basin has two distinct sub-basins and two additional less distinct sub-basins; depths range from 34.7 to 58.2 m, although measures made in May 1997 suggest an even slightly larger maximum depth (60 to 62 m). The south basin drains into the west basin at a wide but shallow isthmus in its southwestern corner. Occasional movement of water from the west basin to the south basin may occur due to wind, but the much greater water load to the south basin dictates flow to the west basin nearly all of the time.

West basin. Bordered by a mix of lightly developed farm and undeveloped land, this basin has no known storm water drainage inlets. The channelized drainage from Lake Szarek enters on the north side. The shoreline is almost entirely vegetated, with a wide fringe of emergent vegetation in many areas. Although the shallowest of the three basins, the west basin still has two distinct sub-basins, each with a maximum depth of 10 m, one east and one west. The Elk River exits Lake Elckie in the west basin along the south side. Fish traps or pens are evident at several places in the western portion of this basin, as well as areas where dredging has been performed along the shoreline.

Precipitation. Data dating from 1930 through 1996 indicates an average precipitation rate of 635 mm/yr with a range of 452 to 725 mm/yr. Flow data from several gauging stations indicate an average flow of 3.78 m^3/s at the Elk River inlet to the south basin, with a "low flow" average (NSQ) of 2.02 m^3/s. Slightly downstream of the lake, the average flow in the Elk River is approximately 3.94 m^3/s with a low flow average (NSQ) of 2.22 m^3/s. Records from the fish hatchery at the northern end of the north basin suggest an average flow from Lake Sunowo of 0.7 m^3/s, split between several hatchery channels. No flow records for other inputs were available.

A2. Chemical Attributes

Chemical data is available for sporadic individual samplings in the 1950s, 1970s, and 1980s, plus various intermittent but more intensive samplings in the 1990s. Deteriorating conditions have been evident from the 1950s into the 1970s with the addition of direct discharge to the lake from a wastewater treatment facility at the mouth of the Elk River. Upgrade and relocation of the facility to a point downstream of Lake Elckie has led to improvement beginning in the late 1980s and continuing into the 1990s.

Lake Elckie s ranking. The lake has not returned to a desirable Class I ranking, however, based on the Polish multiparameter ranking system. The hypolimnetic region of each basin is rated NON (non-attainment of even Class III), largely as a consequence of anoxia and related accumulation of contaminants such as ammonia and phosphorus. The surface waters of the South basin are ranked as Class II, and the surface waters of the north and west basins are considered to be Class III. Though in the Polish ranking system, most parameters carry equal weight, the overall classification of the lake may not be better than that indicated by the fecal coliform count. A lake could therefore be ranked as Class II based on fecal coliform levels, despite better indications from other parameters, but could be ranked as Class III if the other parameters indicated more degraded conditions.

Overview of water analysis. A wide variety of parameters have been assessed, and the following general observations are offered:

- Values for biochemical and chemical oxygen demand are generally moderate although somewhat elevated in the hypolimnetic samples.

- Dissolved oxygen is adequate during spring and autumn, but depressed or absent in the hypolimnion during summer. No winter data are available, but no winter kills of fish have been reported; oxygen depression but not depletion is likely under the ice.

- Hydrogen sulfide is produced in the anoxic zone, suggesting strong redox potential. Sulfates are reduced to provide oxygen under such conditions, leading to the production of toxic and foul-smelling hydrogen sulfide. Available sulfides scavenge iron from the water column in a precipitation reaction, limiting available phosphorus-binding capacity and promoting internal recycling.

- The pH is circumneutral to slightly basic, but not >8 SU; the lowest values are found in the hypolimnion, consistent with acid release during decomposition.

- Conductivity and dissolved solids values are slightly elevated at 340 to 440 μmhos/cm, with highest values in the hypolimnion.

- Major cations and anions (Ca, Mg, Cl, SO_4) are slightly elevated, but not extreme. Alkalinity is moderate to high with levels >100 mg/l as $CaCO_3$ equivalents.

- Iron and manganese levels are largely unknown; one report places in-lake levels of each at <0.01 mg/l, but it seems likely that hypolimnetic values would be higher, especially under anoxia. Values for the input from Lake Sunowo and the fish hatchery appear to range from 0.04 to 0.40 mg/l, and values for the Elk River are reported at 0.03 to 0.17 mg/l.

- Coliform counts were low to moderate; no immediate post-storm values were available, however, for nearshore areas where storm drains discharge.

- Visibility (Secchi disk transparency, or SDT) is low in the summer (<1.0 m and often about 0.3 m), consistent with elevated algal levels as evidenced by chlorophyll concentrations >20 ug/l (typically 23 to 50 ug/l as an epilimnetic average, with higher levels near the surface).

- Nitrogen levels were variable but generally moderate in the lake, while phosphorus levels were also variable but generally elevated in most samplings; this is of critical importance to overall lake condition.

Nitrogen and phosphorus levels. The concentrations of nitrogen and phosphorus largely control productivity and the types of algae present in most freshwater lakes. Certainly other elements are of significance, but eutrophication is most clearly linked to the abundance of nitrogen and phosphorus. Among these two essential plant nutrients, phosphorus is most important in determining the overall abundance of algae, while the nitrogen-to-phosphorus ratio is critical to the types of algae present. Lake management efforts to control algae are most often directed at phosphorus because the phosphorus control methods often limit nitrogen availability, as some forms of algae can fix atmospheric nitrogen and a high nitrogen-to-phosphorus ratio is generally preferred to a low ratio for a desirable algal community.

Nitrogen levels are normally subdivided into nitrate, ammonium, and total Kjeldahl fractions. Ammonium is converted to nitrite and then nitrate fairly quickly in the presence of oxygen, so nitrate is normally more abundant than ammonium in oxygenated waters and ammonium is more common than nitrate under anoxic conditions. Total Kjeldahl nitrogen (TKN) consists of ammonium nitrogen and all organic forms of nitrogen that can be digested in the testing method.

In general, inorganic nitrogen (nitrate + ammonium) in excess of 0.3 mg/l can cause productivity problems, while a value >0.6 mg/l is undesirable and values >1 mg/l usually indicate a substantial problem. Values in the three major basins suggest a range of 0.0 to 2.27 mg/l, with higher values in the anoxic hypolimnion. Total nitrogen or TKN values in excess of 1.0 mg/l can be a concern, and values above 2.0 mg/l usually indicate a problem. Values tend to range from 0.8 to 1.3 mg/l.

Phosphorus levels above 0.02 mg/l can lead to algal blooms, while concentrations >0.05 mg/l are routinely associated with nuisance conditions. Soluble reactive phosphorus values in surface waters ranged from 0.01 to 0.05 mg/l in the north and south basins, suggesting variable conditions for algal growth. Total phosphorus values in the surface waters of the north and south basins tend to be in the same range or slightly higher, with an average of 0.03 mg/l. Phosphorus levels near the bottom were slightly elevated during spring or autumn, at 0.04 to 0.10 mg/l, and were quite high in the hypolimnion during summer stratification at 0.28 to 0.40 mg/l in the north basin and 0.13 to 0.34 mg/l in the south basin. Summer surface values in the west basin average about 0.13 mg/l, while hypolimnetic values range from 0.32 to 0.65 mg/l. The potential for bluegreen algae and flagellated forms to absorb nutrients near the thermocline and then move upward creates the possibility of algal blooms during summer even when surface phosphorus levels are relatively low.

The nitrogen-to-phosphorus ratio is often >20 to 1 in the surface waters, but is sometimes lower in the surface waters and is typically <7 to 1 in the hypolimnion during summer. The lower ratios will tend to favor bluegreen algae and are adverse for human health and ecological processes.

Nitrogen and phosphorus levels in the Elk River are a concern, as both tend to be high. Values of up to 5.5 mg/l of nitrogen and 1.6 mg/l of phosphorus were recorded, with averages of 2.5 mg/l of nitrogen and 0.4 mg/l of phosphorus. Such values indicate substantial inputs and suggest likely sanitary sewage or agricultural contamination. Such inputs are suggested by the regional environmental agency's 1995 summary of regional water quality and land-based influences. The summary noted large loads of nitrogen and phosphorus upstream of Elk. Storm water sampling at selected Elk discharge sites to the Elk River in 1995, after sewerage improvements were made, still suggested high levels of nitrogen and phosphorus in this area as well. Nitrogen and phosphorus input levels to the Elk River, however, are much lower than before sanitary sewage system upgrade and relocation. Nitrogen and phosphorus levels in the Lake Sunowo discharge through the fish hatchery and around it are also elevated, but not so substantially as in the Elk River. Nutrient levels in other tributary or storm water drainage systems are generally unknown, but assumed to be high.

Nitrogen and phosphorus sediment concentrations are substantial. Nitrogen levels range from 5,950 to 10,010 mg/kg in the sediments of the three basins, while phosphorus levels range from 1,270 to 1,860 mg/kg. These high values indicate sanitary sewage or agricultural inputs and probably reflect the inputs of the 1960s and 1970s, especially the discharge from the former waste water treatment facility. Distinct sediment layers have been noted for the north basin, but less layering is apparent in sediments from the south and west basins. Black and gray flecks have been observed on the sediment surface, consistent with anticipated precipitation of iron sulfides and related sulfide complexes.

A3. Biological Attributes

Algae growth. Lake Elckie suffers from summer blooms of bluegreen algae, most notably *Aphanizomenon* and *Oscillatoria,* but also including *Microcystis* and two species of *Anabaena*. Both *Aphanizomenon* and *Oscillatoria* are noted for developing blooms near the thermocline, and *Aphanizomenon* frequently develops gas vesicles and floats upward thereafter. *Aphanizomenon* can be toxic, causing skin rashes or gastroenteritus after contact recreation and killing some would-be zooplankton consumers. Bluegreen blooms were more severe in the 1970s, before the upgrade and relocation of the wastewater treatment facility. Now they tend to be restricted to mid to late summer and early autumn, although blooms during that period can be intense.

Other algae known in the lake include one pennate and three centric diatoms normally associated with eutrophic waters, five chlorococcalean green algae and one desmid, also associated with eutrophic waters, and five flagellated forms common to habitats with high organic carbon content. Spring water clarity is not high, but no reports of severe diatom or green algae blooms were found.

Mats of green or golden algae have also been found in the lake, with *Vaucheria* cited as one problem species. Mats of *Cladophora* or *Rhizoclonium* are known from other Polish lakes with similar problems. These mats develop on fertile bottom sediments in shallow areas, then float to the top after trapping their own photosynthetic gases. Certain bluegreen algae can also form such mats, but are not reported from Lake Elckie. Floating algal mats appear to be mainly a spring phenomenon in Lake Elckie, due to low summer water clarity, and are reportedly not as severe now as in the past.

Rooted plants. These are generally restricted to peripheral areas and include mainly emergent forms. *Phragmites* and/or *Philaris* reeds form dense stands in portions of the west basin, and are found in patches around the north and south basins. Other emergent forms (such as cattails and sedges) are much less abundant, and submergent forms appear restricted to a few species tolerant of low light, most notably *Myriophyllum spicatum*. Fish habitat is compromised by the limited amount of submergent vegetation.

Zooplankton. Cladocerans (both calanoid and cyclopoid copepods) and several common rotifers, with all taxa typical for eutrophic lakes, are present. Daphnia, large-bodied algae grazers and a preferred fish food, are present at low to moderate density, but rotifers and copepods were both more abundant. Predation pressure by small fish in the absence of an oxygenated hypolimnetic refuge (larger zooplankters hide in the dark bottom waters by day if oxygen is sufficient) is likely to be responsible for the zooplankton community structure.

Fish. A typical European warm water fish assemblage is present, including pike, perch, and many cyprinid species. A coregonid whitefish is also present. Fish production is calculated at 18 to 80 kg/ha/yr, which is high but not unusual for the region. Production as high as 120 kg/ha has been reported as possible for Lake Elckie. However, a shift from fewer larger predators toward many more, smaller, planktivorous fish has been observed over the last decade or more. While fishing is still popular, it is not as successful or satisfying as desired by most fisherman.

The lack of oxygen in the colder bottom waters limits support of a large, healthy population of salmonid fishes (trout and salmon), although surface waters do not get extremely warm during summer and salmonid survival is possible. The lack of submergent vegetation limits populations of pike and perch, which prefer such vegetation for cover and reproduction. Other species better adjusted to warm water and limited vegetation (e.g., walleye) might thrive in this system but are not reported as abundant.

Waterbirds are not uncommon at Lake Elckie, but spring densities do not seem as high as might be expected for such a fertile lake. Black ducks, mallards, cormorants, herons, and swans were all observed. Many swallows were seen over the west basin of the lake, probably responding to spring hatches of chironomids. However, no information on benthic invertebrates is available and the strong hydrogen sulfide production suggests a limited benthic invertebrate community except in shallow peripheral areas.

B. Watershed Features

The total watershed of Lake Elckie (a partial map is provided in Figure II-2) is 967 km^2 in area, which is large both in absolute terms and relative to the lake area. The watershed-to-lake area ratio of 253 is large enough to suggest that loading from the watershed will be substantial even in the absence of specific human-oriented inputs. As many upstream lakes can trap pollutants and limit the load to Lake Elckie, the most critical area for management will be direct drainage to the lake, listed at 50 km^2.

Topography. The watershed is generally rather flat, although slopes near the lake can exceed 15 percent in some areas. Soils tend to be sandy. Land use is a mixture of urban, agricultural, and undeveloped forest and meadow. Potential inputs from most developed areas and agricultural lands are of concern. Since, however, the areas downstream of the nearest upstream lake tend to represent the greatest threat and the Town of Elk has little control of areas outside its jurisdiction, management emphasis has been placed on land near the lake and along the Elk River within Elk. The great majority of land draining into Lake Elckie drains first into the Elk River, which discharges to the south basin.

The importance of sources upstream of Elk should not be ignored, however, as the first upstream lake, Lake Haleckie, is reportedly shallow and in a eutrophic condition. The village of Miluki is just south of Lake Haleckie and the village of Straduny is just north of it. The relative

Figure II-2. Lake Elckie Watershed

importance of current sources within Elk and upstream of it is not clear from the available data; both may require further attention to achieve desirable conditions in the Elk River.

The drainage pattern for this watershed is somewhat complicated by flat topography in many areas and multiple drainage channels interconnecting wetland areas and water bodies. Water may flow between sub-basins in either direction depending on localized conditions. The partial watershed map (Figure II-2) provides a reasonable approximation of the major sub-basins relating to Lake Elckie.

Major pollutant sources. Sources of pollution include sanitary sewage (although greatly reduced over the last decade in Elk) and urban and agricultural runoff. Agricultural runoff can contain fertilizers and manure, or simply nutrient-rich soil, if not properly managed. In general, agricultural management in the vicinity of the lake is commendable. The farm west of the north basin has 80 dairy cows, about 70 beef cattle, and two horses, along with substantial crop lands to support these animals and extensive vegetable gardens tended by area residents. Little of the farm area drains directly to the north basin as a result of natural and adjusted land contours, and there are no current piped drainage systems or swales connected to the north basin. Straw is used in stalls to absorb wastes, manure is collected in a pit and spread in a designated area away from watercourses, and grazing is conducted out of the direct drainage area. A dense cover crop used for hay and including mostly clover is found in the area which does drain directly to the lake.

The farm and adjacent residential area have a community wastewater disposal system that is reportedly a tight tank. Frequent pumping with transport to the wastewater treatment facility is necessary. A suspected overflow pipe to the lake is under investigation by the Town of Elk, but no problems were apparent. Water flow to the residential area west of the north basin is controlled by the town, and wastewater generation is monitored.

Agricultural influences. A few agricultural improvements could be implemented around the west basin (e.g., keeping cows out of the lake and plowing parallel to slope contours), and the use of fertilizers everywhere should be reviewed for appropriate quantity and nutrient ratio (e.g., the farm west of the north basin uses a fertilizer mix with a low nitrogen-to-phosphorus ratio (100 parts to 60 parts). In general, however, agriculture does not appear to be a major local influence on the lake. Practices further away in the watershed have not been documented in this program.

An alternative agricultural activity within the watershed of the north basin is the fish hatchery, where rainbow trout, sturgeon, goldfish, and several other species are raised in raceways fed by water from upstream Lake Sunowo. Carp ponds are also maintained, and fishing is available to the public for a fee at the main pond, through which most Lake Sunowo water passes. About a third of the upstream lake discharge, which averages 700 l/s, is routed through the raceways. There waters are exposed to fish wastes, held in a small pond briefly, and then discharged to the north basin of Lake Elckie. Much of the time, the water leaving the fish hatchery is of a quality similar to that from Lake Sunowo, which is a requirement of the water use. The Lake Sunowo water, however, is not of especially high quality, and phosphorus inputs from this source are a concern for the north basin.

Urban runoff. This includes contaminants from many different sources, including atmospherically delivered pollutants such as car and truck emissions, oil and grease, and runoff from yards, which would become part of the soil if the land were forest or farm. Storm drainage systems, necessary to avoid flood hazards, often deliver these pollutants to the aquatic environment with minimal attenuation of the load. This appears to the case with most of the Elk drainage systems, although installation of grease and grit traps (sometimes called sand separators) has begun. Although the capture of coarse particles and floatable solids will reduce the current urban runoff pollution load, dissolved pollutants are not trapped to any great degree and will not be much reduced by separators.

Storm water. There are 16 storm water drainage systems discharging into the Elk River in the Town of Elk, five of which are large systems. Another large drainage system is planned for future development to minimize flood hazard. Most discharge pipe diameters are 0.5 to 1.2 m in diameter, suggesting a substantial capacity. Combined sewer overflows have been a problem in the past, but aggressive efforts to separate sanitary and storm sewers continue. Data from 1995 suggest that there was still sewage contamination of the storm water drainage system after the initial round of sewer improvements, but current runoff quality has not been quantified.

Sanitary sewage. The extension of sanitary sewer service and upgrading and relocation of the wastewater treatment facility in Elk have greatly reduced the input of sewage to the lake. Further work is planned. The reduction in phosphorus load, described later, is quite large. The ability to control upstream sanitary sewage or agricultural inputs is limited, but such action may be needed in the future. Limited water quality data for the Elk River from 1991 and 1992 suggest high levels of nutrients and other contaminants upstream of Elk, with only modest increases in pollutant loads within the boundary of Elk. The villages of Straduny and Miluki (upstream and downstream of Lake Haleckie, respectively) may be important in the observed pollutant load, but problems in many upstream lakes indicate more widespread inputs from the larger watershed.

Erosion. The Elk River and other tributary systems are generally stable and not subject to major erosion problems. Slopes are slight. Accumulated sludges in the Elk River could be a continuing concern, but data are not sufficient for determining the feasibility of removal. Generally, dredging of rivers for pollutant removal has been less successful than desired in many other systems, and often unnecessary to achieve the desired improvement in downstream lakes. Actual removal of accumulated sludges is certainly desirable, but has been difficult to achieve without substantial downstream distribution of contaminants.

Shoreline erosion is not extreme, but a few areas of intensive access along the east side of the south basin need attention. This is more an aesthetic issue than a major pollution factor. Several erosion areas along the shoreline have already been remediated by the Town of Elk, and officials are well aware of remaining problem spots.

There is a former landfill in the watershed of Lake Sunowo, which drains into the north basin of Lake Elckie. Leachate from this landfill is believed to contaminate Lake Sunowo, but no further information on its effects was reviewed in this investigation.

Watershed. A recently completed thesis project provides substantial land-use and pollutant source data for the immediate watershed of Lake Elckie. Although the entire watershed is not covered, the potential threats within the direct drainage area and some locations beyond have been identified. Additional investigation with this pollution hazard map could be an efficient way to pinpoint the most critical inputs and sources.

The Biebrza area downstream of Elk includes a national park and many additional lakes. Management of the Lake Elckie watershed and in-lake conditions is perceived as beneficial to the health of the larger watershed system encompassing Biebrza. While watershed management needs still exist, and will always be necessary for the continued health of area lakes, the Town of Elk has done much to improve conditions already and is demonstrating regional if not national leadership in lake and watershed management. Compared with many other Polish lake and watershed systems (Kudelska 1992), the Town of Elk has taken a much more comprehensive approach to water quality management.

C. Hydrologic Evaluation

Based mainly on flow data for the Elk River, the approximate detention time for the south basin is three to four months (Kufel 1996). A more detailed, if somewhat speculative, hydrologic evaluation is provided in Annex B. In this evaluation, the three basins of Lake Elckie are treated separately, and the perceived hydrologic variability of these basins is evident. Throughflow for the north basin is estimated at 23,568,000 m^3/yr, or 0.75 m^3/s, with most water supplied by Lake Sunowo. Resulting detention time is 120 days on average, suggesting three flushes per year. Seasonality of inputs is clear, however, and summer detention is likely to be extended for the upper as well as the lower water layer.

The total water load to the south basin is estimated at 146,417,000 m^3/yr, or 4.64 m^3/s. Most water comes from the Elk River. This results in a detention time of about 112 days and 3.3 flushes per year, which is consistent with past estimates. This may be a slight overestimate, as evaporative losses from the north basin before discharge to the south basin have not been subtracted. However, separation of the large hypolimnion modifies the interpretation of this detention time. Reduced summer flows are offset by the reduced interacting volume, such that summer detention is probably still close to the average, or even less. The hypolimnion waters are not exchanged during this period, but some vertical transport of pollutants is likely.

The flow through the west basin is little more than the outflow from the south basin, at 149,813,000 m^3/yr or 4.76 m^3/s. This may be a slight overestimate as with the south basin, as evaporative losses from the south basin have not been subtracted, but it is expected to be a close approximation of actual throughflow. The resulting detention time is only 12 days and the flushing rate is 31.5 times per year. Variability may be appreciable, as a substantial portion of the lake is west of the Elk River outlet, but flushing is probably rarely less than once per month. The small hypolimnion is not a major factor.

The downstream flow record for the Elk River suggests an average value of 3.94 m^3/sec, suggesting that about 0.82 m^3/s of the total calculated water load would be lost to evaporation or ground water outflow. This is in line with normal expectations. The estimated hydrologic load suggests a water yield of 0.4 to 0.5 m^3/s for each 100 km^2 of watershed. This seems low, but the region is relatively flat and mostly vegetated.

SECTION III
OXYGEN LOSS AND PHOSPHORUS LOADING EVALUATION

Calculations associated with the estimates presented in this section are provided in Annex B. The best available data were used to derive these estimates, but a number of literature values and assumptions had to be applied to complete the calculations. While these estimates are believed to be appropriate, they should be re-evaluated as future data become available.

A. Dissolved Oxygen Deficit

Knowledge of the degree of oxygen demand is essential to assessing possible management actions. The loss of dissolved oxygen from the lake through decomposition of organic material can be offset by atmospheric inputs at the surface, but the separation of the hypolimnion from the epilimnion during summer stratification prevents oxygen from reaching the bottom layer. With continuing decomposition, oxygen levels in the bottom layer decline and may become depleted. In the absence of oxygen, most fish cannot survive in the hypolimnion, ammonium cannot be oxidized to form nitrate, and anaerobic metabolism results. With continued intense demand for oxygen, anaerobic organisms will reduce nitrate and then sulfate to get oxygen, forming nitrogen and sulfide gases as byproducts. The presence of hydrogen sulfide at the bottom of all three basins of Lake Elckie indicates a strong oxygen demand and high reduction-oxidation (redox) potential. Under such conditions, phosphorus bound in certain compounds in the sediments is readily released back into the water column.

Calculation of the oxygen deficit rate (ODR) is usually performed with data representing the hypolimnion shortly after stratification and before oxygen declines to <1 mg/l. This is because as oxygen decreases, it becomes harder for the demand to be expressed, since the decrease is not linear. For Lake Elckie, with only limited data available, we have had to estimate ODR at an endpoint with no dissolved oxygen. Consequently, the resulting estimates are certainly underestimates.

Resulting ODR for the north basin is 764 mg/m^2/d, which over the area of the hypolimnion equates to a loss of 428 kg/d, and over the volume of the hypolimnion amounts to a decrease of 0.26 mg/l/d. Based on experience elsewhere, the actual demand is likely to be about twice this amount, at 1,530 mg/m^2/d, 860 kg/d, or 0.52 mg/l/d (Cooke et al. 1993). For the south basin, the ODR is calculated at 2,943 mg/m^2/d, which over the area of the hypolimnion equates to a loss of 5,004 kg/d and over the volume of the hypolimnion amounts to a decrease of 0.22 mg/l/d. Applying the rationale that actual ODR is about twice the measured ODR, the actual demand for the south basin is likely to be about 5,900 mg/m^2/d, 10,000 kg/d, or 0.44 mg/l/d. Values for the ODR >550 mg/m^2/d are considered indicative of eutrophic conditions.

The west basin represents a special case, as it is minimally stratified. Calculation of ODR by difference in oxygen levels over time is therefore not possible for most of the lake area, yet an ODR surely exists over the entire lake area. Loss of oxygen in most of the water column due to sediment demand is most likely counteracted by atmospheric input. The sediment demand is still present, but its impact is not expressed in most of the lake volume. Oxygen does not diffuse rapidly enough to counteract the sediment oxygen demand, and oxygen levels right at the sediment-water interface are believed to be negligible. Under these conditions, phosphorus release and hydrogen sulfide production can still occur. It is assumed that the oxygen demand in the west basin is similar to that in the south basin. Expressing the ODR on an areal basis at 5,900 mg/m^2/d, the total oxygen loss would be about 6,900 kg/d. Using a volumetric ODR value of 0.44 mg/l/d, the total oxygen loss would be about 2,100 kg/d.

It may not be necessary to completely offset the ODR to prevent oxygen depletion at the bottom of each basin, but a substantial amount of oxygen will be necessary on a regular basis. If enough oxygen is added to oxidize the sediments and inputs of new oxygen demanding substances are decreased, it may be possible to cease further oxygen inputs, but achieving such a condition is unusual in lake management.

B. Internal Phosphorus Release

Much of the phosphorus entering Lake Elckie is eventually accumulated in the bottom sediments of the lake. Most phosphorus enters the lake in a particulate form and can settle readily upon entry. For phosphorus entering in dissolved form, sedimentation processes include adsorption to particles and uptake by algae with subsequent settling. Once on the bottom, the phosphorus may be further immobilized by burial or reaction with compounds to form more inert materials. Some phosphorus may be taken up through the roots of plants and be incorporated into plant tissue. Where phosphorus is bound in organic particles, decomposition may release it back into the water column. When anoxia occurs, phosphorus bound by iron and manganese (two common metals to which sediment-bound phosphorus is often attached) may be released back into the water column. Phosphorus bound by calcium or aluminum, two other common phosphorus binders, is not sensitive to oxygen level but may release the phosphorus at extreme pH. Some small amount of phosphorus release from sediments is likely in all lakes, but under anoxia this release tends to be greatly accelerated. Where a lake may be significantly impacted by either watershed inputs or internal recycling, it is important to have an estimate of phosphorus release when evaluating the benefit from possible management actions.

Calculations of phosphorus release in Lake Elckie (Annex B) are based on the accumulation of phosphorus in the anoxic hypolimnion, or in the case of the west basin, on the difference between observed concentrations and the concentration expected from other inputs. For the north basin, the internal release is estimated at 12.5 kg/d, which equates with a release of 22.2 mg/m^2/d and results in a summer load of 1,125 kg of phosphorus. For the south basin, the internal release is estimated at 54.4 kg/d, which equates with a release of 32 mg/m^2/d and results in a summer load of about 4,900 kg of phosphorus.

The west basin represents a special case, as there is only a small hypolimnetic volume in which phosphorus can accumulate, yet substantial release from much of the bottom area is expected based on oxygen demand. Using the phosphorus accumulation approach, an estimate of only 0.7 kg/d is obtained, or 4.6 mg/m^2/d, but this is unrealistically low. Inputs from other sources (Annex B) are estimated at a minimum of 4,800 kg, resulting in an expected concentration of 0.03 mg/l. About 0.10 mg/l more must enter the lake to achieve the observed concentration of 0.130 mg/l, suggesting an additional load above 15,000 kg/yr, or a release rate of 35.6 mg/m^2/d, which is similar to that observed in the south basin.

For the west basin, the amount of phosphorus which becomes available from internal recycling will depend upon how fast that it is bound and re-sedimented in the lake or flows out via the Elk River. There is no reliable data for outflow concentration or available phosphorus binders such as iron in the lake, but modeling of the load necessary to achieve the observed in-lake phosphorus level suggests that much of the internally recycled phosphorus may be readily available, and what little data we have for iron (the most common natural phosphorus binder) suggests that it is in short supply.

For the other two basins (north and south), it is not certain how much of the hypolimnetic phosphorus is able to pass into the epilimnion during the summer growing season. Limited data for iron indicates that there is not enough of this element present to bind all the phosphorus under oxic conditions, and the presence of hydrogen sulfide in the hypolimnion indicates chemical conditions under which phosphorus may readily diffuse across the thermocline into the upper water level. At least 10 percent and maybe as much as 50 percent of the recycled phosphorus may move into the upper water levels during summer and fuel algal growths. At the least, populations of certain algae may take advantage of the phosphorus level near the thermocline to accumulate phosphorus, then float upward to obtain more light and achieve bloom conditions. More iron (or a substitute phosphorus binder) and less hydrogen sulfide (which binds iron before it can combine with phosphorus) is likely to be necessary to reduce the internal load in the north and south basins.

Former phosphorus load from sanitary sewage. A wastewater treatment facility used to be located at the mouth of the Elk River and discharged directly into Lake Elckie. The best available estimate of the former load of phosphorus to Lake Elckie from sanitary sewage is 29,200 to 43,800 kg/yr, based on known flows and typical wastewater phosphorus levels. This was an overwhelming load to the lake, and the strong anoxia and internal phosphorus recycling are lasting effects of these past inputs. The elimination of further inputs of this magnitude was an essential first step in lake restoration.

Current phosphorus load from sanitary sewage. The wastewater treatment facility was upgraded to tertiary treatment with nitrogen and phosphorus removal and relocated to a point downstream of Lake Elckie, with discharge to the Elk River downstream of the lake. One estimate of current direct loading of phosphorus to Lake Elckie from sanitary sewage is 42 to 210 kg/yr to the north basin and a similar amount to the south basin, based on 10 percent of the population remaining off the sewer line and on septic systems, with 1 to 5 percent of the load reaching the lake. Inputs to the Elk River via the storm water drainage system could be much higher, however, and illegal hook-ups from sanitary waste lines to the storm water drainage system have been reported. Provision of properly separated sanitary sewers is continuing, but the decrease in loading particularly to the south basin, is already extreme and highly commendable.

Direct phosphorus load from urban runoff. Little data exist to aid estimation of the load of phosphorus from urban runoff. Based on assumptions about the drainage area, production of runoff, average phosphorus level in that runoff, and average annual export of phosphorus from urban land, an estimate of 50 to 100 kg/yr was derived for the north basin and 150 to 300 kg/yr for the south basin. No direct inputs of urban runoff are known for the west basin. Some of the current sanitary sewage load to the lake is probably included in the urban runoff by means of infiltration of storm water drainage pipes, but sewage impacts have been excluded from these estimates of phosphorus load in runoff. The load of urban runoff to the Elk River is also excluded from these estimates and is considered separately.

Phosphorus load from Elk River to south basin. The Elk River is the largest tributary to Lake Elckie, and is a major influence on hydrology in the south and west basins. Flow records are substantial, but water quality data are scarce. Based on the best available data, a phosphorus input estimate of 12,700 to 47,700 kg/yr has been derived. Of this total, about 1,000 to 2,000 kg/yr appear to be coming from urban runoff in the Town of Elk. A load of 7,500 kg appears to be coming from upstream sources not directly under the control of Elk officials, based on a 1995 memorandum from the regional environmental agency. This would suggest that sanitary sewage inputs from Elk still contribute at least 3,000 kg of phosphorus per year as of 1995, but the data are limited and any such calculation is highly speculative. It is true, however, that a 1995 sampling of several storm drain discharges yielded data indicating continued sewage inputs. Further monitoring is needed to clarify current Elk River inputs to Lake Elckie and the relative importance of contributing sources.

Direct phosphorus load from agricultural land. No data exist for agricultural inputs in this system, but based on typical export of phosphorus from agricultural lands, estimates have been derived. The expected load is about 8 to 24 kg/yr for the north basin, and 300 kg/yr for the west basin. There are no known agricultural inputs to the south basin.

Phosphorus load from fish farm to north basin. The fish hatchery at the north end of the north basin uses water from Lake Sunowo for its fish rearing raceways, provides some detention time in a small pond, then discharges the water to the north basin. Based on data from the hatchery, the load to the north basin could be between 300 and 2,800 kg/yr, with an expected average of about 600 kg/yr.

Phosphorus load from Lake Sunowo to north basin. Water not used in the fish hatchery operation is passed from Lake Sunowo through the hatchery property and into the north basin. Based on data from the hatchery, which monitors water quality and flow, the load from Lake Sunowo to the north basin of Lake Elckie, exclusive of any hatchery inputs, is between 1,450 and 2,900 kg/yr, with an expected average of almost 2,200 kg/yr.

Phosphorus load from Lake Szyba to south basin. Lake Szyba can overflow to the south basin of Lake Elckie from the east. There are no data available for this input, but rough calculations using typical values for a watershed area of appropriate size and what is reported as clean conditions suggest a phosphorus load of only about 3 kg/yr.

Phosphorus load from Lake Szarek to west basin. Lake Szarek drains into the west basin of Lake Elckie from the northwest. No data are available for this input, but rough calculations using typical values for a watershed area of appropriate size and what is reported as slightly degraded conditions suggest a phosphorus load of about 80 kg/yr.

C. Total Phosphorus Load to Lake Elckie System

In-lake models. One approach to estimating the total phosphorus load to a lake or basin is to work backward from a known concentration in the lake to calculate the load which should have been entered to create that observed concentration. Something must be known about in-lake conditions, system hydrology, and the processes that affect incoming phosphorus. What is calculated is the load that the lake appears to be experiencing, or the “effective load.” The actual load may be substantially higher, but the additional phosphorus is not being used in active lake metabolism. This additional phosphorus may either become part of the sediment base (from which it can be recycled) or pass through the lake unused.

Using a series of four computerized models, load estimates were derived for each basin of Lake Elckie. Based on these models (Vollenweider 1975, Kirchner and Dillon 1975, Jones and Bachmann 1976, and Larsen and Mercier, 1976), the effective load to the north basin is 777 to 1,113 kg/yr, with an average of 953 kg/yr. For the south basin, the range is 4,594 to 6,825 kg/yr, with an average of 5,538 kg/yr. For the west basin, the range is 19,878 to 23,664 kg/yr and the average load is 21,791 kg/yr.

Itemized loading estimate. Although speculatively based on the available information, an overall loading table (Table III-1) has been constructed to illustrate the apparent loading of phosphorus to each basin of Lake Elckie. It incorporates information for sources including precipitation, ground water (which includes sanitary sewage in this case), direct urban and agricultural runoff, tributary inputs, and transfers among the three basins (north to south and south to west). The resulting total loads are estimated at an average of 4,077 kg/yr for the north basin, 53,697 kg/yr for the south basin, and 8,154 kg/yr for the west basin.

These loads are the initial inputs to each basin, however, and not the “effective load” as described previously. They also do not completely address the internal load to each basin, tending to emphasize the possible summer load. The component estimates are useful in evaluating the relative magnitude of sources, but some additional interpretation of the effective load and its seasonal pattern is needed to prepare for an evaluation of management options.

Best estimate of current loading. In Table III-1, there is a column for the effective input to each basin, which is the amount of phosphorus from each source that is actually utilized in the lake, based on professional judgement. Excess phosphorus would either become part of the sediment or pass through the lake unused, as described previously. For the north basin, the effective load is estimated at 874 to 1,324 kg/yr. This assumes utilization of about half of the precipitation phosphorus input, 10 percent of the groundwater input, 50 percent of the urban runoff input, 75 percent of the agricultural input, and 25 percent of the input from the fish hatchery and Lake Sunowo; only the summer internal load is important; and only 10 to 50 percent of it is available. These assumptions are based on experience with similar lakes, but they are still assumptions and not proven for this system. They are, however, consistent with what appears to be occurring in the lake, and alteration of these assumptions by $\pm$50 percent seems to have little impact on the conclusions drawn from the loading analysis. Until better information can be collected, this analysis is put forth as a basis for interim management planning.

For the south basin, the estimated effective load is 5,484 to 7,494 kg/yr, which suggests that most Elk River input becomes part of the south basin sediment base or passes into the west basin. It is hard to believe that only 10 percent of the Elk River load becomes immediately available, but if a greater percentage is assumed, the modeled effective load (shown in Table III-1) is greatly exceeded. The conditions in the south basin (algae, water clarity) do not reflect higher inputs than suggested by the models. It would be helpful to determine the accuracy of the estimate of Elk River inputs and evaluate mixing of that input in the south basin. Knowledge of how much of the Elk River load passes into the west basin is important to understanding loading processes in the west basin as well.

The estimated effective load to the west basin is between 7,972 and 2,4238 kg/yr, including estimates of both summer and annual internal loading and creating a wider range than for the other basins. The key question for the west basin is whether the inputs from the south basin or the internal load is more important to phosphorus concentration. The answer cannot be determined from the available data, but it appears likely that inputs to the south basin would be fairly thoroughly mixed with more than a two-month detention time, a minimum for that basin. Consequently, it is probable that the higher phosphorus concentration in the west basin is a function of internal recycling.

Table III-1. Postulated Hydrologic and Phosphorus Loads to Lake Elckie

Beyond consideration of the effective load, the seasonal pattern of loading is important. The internal load to each basin is likely to be concentrated in the summer, during the growing season when algae can make the most use of available phosphorus. For the north basin, the flow from Lake Sunowo is at a maximum in the spring and a minimum during summer, on average, suggesting that by late summer it should have less influence on conditions than internal loading. Flows from the Elk River into the south basin will also decline during summer, but appear to remain significant for that basin. Inputs from other surface water sources will also tend to decline during the summer, but bursts of loading due to runoff from summer storms could carry substantial nutrient inputs. Groundwater inputs, along with any associated sanitary sewage load, will be relatively constant when compared with surface water sources, as will be the fish hatchery load.

The longer detention times of the north and south basins suggest that spring and summer inputs will be most critical to lake conditions, especially during summer. A portion of all inputs will contribute to the long-term internal reserves which comprise the internal load. Management of watershed loads to the lake during spring and summer will be most useful in controlling algal blooms and other pollution events during the period of major human use, but most actions in the watershed (e.g., sanitary sewage and storm water management) tend to reduce the intended sources through much of the year. In-lake actions intended to combat inputs already in the lake should be geared toward the late spring and summer, unless fall-winter activity can be clearly demonstrated to provide lasting benefits.

For the west basin, with a short average detention time of about 12 days, conditions will be largely a function of what happened during the preceding week to month. Inputs from the south basin, unless there is short circuiting of the Elk River flows, will tend to stabilize conditions in the west basin through stable flushing. However, the quality of water entering from the south basin is suboptimal. Adding the influence from potentially intense internal recycling in the west basin, conditions are expected to be rather poor, even if stable. Summer reduction in phosphorus load to the west basin could provide substantial improvement without addressing loading at other times of the year, but the large volume of the south basin suggests that alteration of its influence will be difficult, and the dependence of internal load on long-term past inputs further complicates application of any “quick fix” in the west basin.

D. Desired Phosphorus Load

Using a standard Vollenweider analysis (Vollenweider 1968) of phosphorus load in relation to basin detention time and depth, the boundary limits for desirable and undesirable loading can be determined. The permissible or admissible load is the amount below which no serious algal blooms or related lake problems would be expected, while the critical or hazardous load would be the amount above which problems would be almost certain to occur. The loading levels in between these two values form the transition zone. It is not necessary to reduce loading to the permissible level to provide satisfactory swimming opportunity and aesthetic appeal, and it may be undesirable to reduce loads much below the permissible level where fish production is a desired objective of management. However, it is almost never desirable for a multi-use lake to have a load in excess of the critical limit.

For the north basin, with a detention time of about 120 days and a mean depth of 9.7 m, the permissible load is 436 kg/yr and the critical load is 871 kg/yr. For the south basin, with a detention time of about 112 days and a mean depth of 24.2 m, the permissible load is 1,652 kg/yr and the critical load is 3,304 kg/yr. For the West basin, with a detention time of about 12 days and a mean depth of 4.1 m, the permissible load is 1,325 kg/yr and the critical load is 2651 kg/yr.

By comparison, the estimated effective load to each basin (from either the itemized load or the models) is greater than the corresponding critical load, indicating that there will be algal blooms and related lake problems under the current loading situation. This is of course consistent with reports for the lake over the last few decades. Conditions appear to have gotten somewhat better following the decrease in sanitary sewage input, but the current loading estimates are still in excess of the critical limit.

The load to the north basin is not far above the critical load, and the importance of summer internal loading appears large. Although the spring-summer load from the fish hatchery and the spring load from Lake Sunowo should not be completely ignored, there is great potential to obtain a marked improvement in conditions through control of summer internal loading. The load could be decreased below the critical load, and the permissible load could be approached for at least the summer season.

The load to the south basin needs to be cut roughly in half to provide conditions that facilitate swimming and aesthetic appeal. It appears that some action relating to both the Elk River and the internal load is needed, but further data would be helpful in determining the action to take.

The load to the west basin is far in excess of the critical load, and it is uncertain whether inputs from the south basin or internal recycling are more influential in this basin. Some attention to both major sources may be essential, but productivity problems are likely to persist in this basin. Even the cleanest water entering this basin would be impacted by the apparent current flux of nutrients from the sediments in this shallow basin, and the presence of clear water would probably result in growth of a dense rooted plant assemblage in this shallow basin. It may be possible, however, to greatly enhance the fishery potential of the West basin by limiting phosphorus availability during summer through in-lake methods. The short detention time in the West basin dictates that remedial actions will have a more rapid effect but a shorter duration of effectiveness than in the other basins.

Current conditions regarding phosphorus, chlorophyll, and water clarity (Secchi disc transparency) are graphed in Figure III-1. Both the north and south basins are in a position to improve substantially with a relatively small reduction in phosphorus concentration, although the desired concentration change in the south basin corresponds to a rather large load reduction as a function of large volume. The west basin is still far from a desirable phosphorus level, and loading reductions could require considerable and continual effort. However, based on the limited available data, the production of algae per unit of phosphorus is not as great in the west basin as in the north and south basins. This is probably a function of detention time, as the west basin is flushed more frequently. Although far more productive, the amount of biomass that can accumulate between flushes is limited.

Figure III-1. Current Phosphorus, Chlorophyll, and Water Clarity Conditions

SECTION IV
MANAGEMENT OPTIONS

A. No-Action Alternative

Taking no action to reduce nutrient loading or the circulation of oxygen is an option, but not a welcome one. No further improvement in Lake Elckie is expected in the absence of further action, and conditions could deteriorate further over time. Taking no action will not accomplish the town's goals, and too much has been done already to stop now without a loss of investment. Further investment is necessary to achieve the goals outlined earlier and presented in Annex C, but some of those goals could be achieved in the near future after years of effort. The no-action alternative is not really a viable alternative and would only be pursued in the absence of funds.

B. Reducing Health and Ecological Threats

The major health and ecological threats associated with Lake Elckie are clear:

- High localized fecal coliform levels.
- Depleted hypolimnetic oxygen and associated build-up of ammonia and hydrogen sulfide.
- Contaminant inputs associated with urban or agricultural runoff.
- Possible impacts from severe algal blooms of toxic varieties.

The fecal coliform problem is partly a function of sanitary sewage disposal problems, which are well on the way to being solved. Fecal coliform inputs are also associated with storm water inputs, along with a variety of other contaminants (e.g., metals and hydrocarbons). Storm water problems are also being addressed, although progress is slower than for the sanitary sewers. Continuation of the present work on sanitary and storm sewer upgrade will handle most of the real threats to human health and should be encouraged. The use of grease and grit traps in the storm sewers may need to be augmented with some method of trapping dissolved pollutants, such as infiltration to the soil or small wetland detention areas near the outlets, but initial efforts should be completed first and some monitoring performed to evaluate the remaining load before proceeding to the next phase of water quality management.

Control of agricultural inputs would be best handled through the use of buffer strips between intense use areas and the lake or its tributaries, with minimization of any direct piping or ditches that could convey runoff directly to the lake or its tributaries. The buffer areas should be minimally fertilized, but could be used for hay production. Dense, mixed cover crops are recommended, with a buffer strip width of from 30 to 75 m.

Control of algal blooms, addressed in Section C, is also a threat to overall lake ecology. The other major threat to lake ecology is the hypolimnetic oxygen depletion. Oxygen depletion can only be prevented by removal of the material demanding the oxygen or addition of sufficient oxygen to offset the demand. Dredging in the deeper parts of Lake Elckie is infeasible. Addition of oxygen through aeration is discussed in Section C. Aeration would provide substantial benefits to multiple uses of the lake and is highly desirable, but not inexpensive.

Management of health and ecological threats is largely a function of maximizing water clarity by minimizing inputs and increasing the oxygen level in the bottom waters of the lake. The Town of Elk has made a good start of watershed management and simply needs to continue on its present course, with refinement as new information dictates.

One additional problem, which is perhaps more a safety than a health concern, involves the large amount of woody debris and the darker color of water in the swimming cove of the south basin. Decay of bark and other wood products (remnants of the storage of logs before use in the mill) is likely responsible for the water color and periodic buoyancy of debris. The result is interference with swimming, either as a matter of aesthetics or actual safety hazard. There are two solutions to this problem.

The first approach is to dredge out the swimming area or entire cover. This would require a hydraulic dredge under most circumstances, at a cost of about $10/m^3 removed. Assuming a work area of about 2 to 3 ha, with only the first meter of sediment removed, the cost would be from $200,000 to $300,000.

The second approach is to bury the offending materials under clean sand. With 0.5 m of sand over the swimming area bottom, at a cost of about $5/m^3 of sand, the burial cost would be about $50,000 to $75,000. As long as the existing bottom materials are firm enough to support the sand, economically this would be the preferred choice.

C. Improving Water Clarity

Improving water clarity is equivalent to controlling algal blooms in this system. The control of algae in Lake Elckie could involve any combination of the techniques described in Table IV-1 (pages 29-30). Attacking the source of the problem—excessive phosphorus levels—instead of the symptoms—the algae blooms—would be most desirable. This would eliminate from consideration algaecides, dyes, settling agents, and even biological controls. Biological controls, especially increasing the abundance of zooplankton that eat algae, would be desirable from the perspective of fueling the food web, but this approach is unlikely to prevent blooms when high levels of available phosphorus are present. Algaecides might be applied as an occasional control but are not a valid long-term approach for a variety of ecological and practical reasons, and recurrent algal blooms would be expected.

Of the remaining techniques, nutrient input reduction stands out as the most universally agreeable course of action. However, as described earlier in this report, achievable control of watershed inputs may not be sufficient to prevent algal blooms as a consequence of the large internal load of phosphorus. While some effort to minimize watershed inputs is desirable, additional in-lake action will almost certainly be necessary.

Based on what we know of the watershed and related inputs, continued sanitary sewer improvements and storm water management efforts (mainly grease and grit traps) are justifiable. What has been done so far in these areas has set the stage for in-lake improvements. Further such actions will provide a safety margin and may be important to preventing short duration problems such as fecal coliform or other localized water quality problems (see section on health impacts). Additional watershed management needs may be out of the jurisdiction of Elk authorities, however, as problems in the watershed of Lake Sunowo and upstream on the Elk River beyond the town boundary may be influential. Additional monitoring, however, is necessary before any action can be planned.

Table IV-1. Management Options for Control of Algae

Option	Mode of Action	Positive Impacts	Negative Impacts
Chemical treatment	Liquid or pelletized algaecides applied to target area. Algae killed by direct toxicity or metabolic interference. Typically requires application at least once/yr.	Rapid elimination of algae from water column with increased water clarity. May result in net movement of nutrients to bottom of lake.	Possible toxicity to non-target areas or species of plants/ animals. Restrictions on water use for varying time after treatment. Increased oxygen demand and possible toxicity from decaying algae. Possible recycling of nutrients, allowing other growths.
Addition of settling agents	Lime, alum, or polymers applied, usually as a liquid slurry. Creates a floc with algae and other suspended particles. Floc settles to bottom of lake. Re-application necessary at least once/yr.	Removes algae and increases water clarity without lysing most cells. Reduces nutrient recycling. Removes non-algal particles as well as algae. May reduce dissolved nutrient levels.	Possible impacts on aquatic fauna. Resuspension possible. Increased sediment accumulation.
Phosphorus inactivation	Typically salts of aluminum, iron or calcium are added in slurry form to the lake. Phosphorus is complexed and settled to the bottom of the lake. Permanence of binding is related mainly to redox potential and pH, with aluminum providing strongest binding. Can be used on inlet streams .	May remove other nutrients and contaminants as well as phosphorus. Flexible with regard to depth of application and speed of improvement. If floc is sufficient, phosphorus in surficial sediments will also be inactivated.	Possible toxicity to fish and invertebrates by aluminum. Possible resuspension of floc. Possible release of phosphorus under anoxia/low pH. May cause fluctuations in water chemistry, especially pH. May add to sediment build-up.
Aeration/ destratification	Addition of air or oxygen at varying depth provides oxic conditions. May maintain or break stratification. Can also withdraw water, oxygenate, then replace	Oxic conditions promote binding/sedimentation of phosphorus. Counteraction of anoxia improves habitat for fish/invertebrates. Deep build-up of ammonia and phosphorus reduced.	May disrupt thermal layers important to fish community. May promote supersaturation with gases harmful to fish.
Dilution/ flushing	Addition of water of better quality dilutes nutrients Addition of water of similar or poorer quality flushes system to minimize algal build-up May be continuous or periodic additions.	Dilution reduces nutrient concentrations without altering load. Flushing minimizes detention, response to pollutants may be reduced.	Diverts water from other uses. Flushing may wash desirable zooplankton from lake. Use of poorer quality water increases loads. Possible downstream impacts.

Option	Mode of Action	Positive Impacts	Negative Impacts
Circulation	Use of water or air to keep water in motion. Often combined with surface aeration or flushing options. Generally driven by mechanical force.	Reduces surface build-up of algal scums. Promotes uniform appearance. Can eliminate localized problems without obvious impact on whole lake.	May spread localized impacts. May increase oxygen demand at greater depths. May promote downstream impacts.
Hypolimnetic withdrawal	Discharge of bottom water which is likely to contain higher nutrient levels and low oxygen. May be pumped or utilize passive head differential.	Removes poorer quality water form lake. May increase bottom oxygen levels. May remove initial phase of algal blooms in deep water.	Possible downstream impacts. May eliminate colder thermal layer important to certain fish. May promote mixing of some remaining poor quality bottom water with surface waters.
Dredging	Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering. Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system. Nutrient reserves are removed and algal growth can be limited by nutrient availability.	Can control algae if internal recycling is main nutrient source. Increases water depth. Can reduce pollutant reserves. Can reduce sediment oxygen demand. Can improve spawning habitat for many fish species. Allows complete renovation of aquatic ecosystem.	Temporarily removes benthic invertebrates. May create turbidity. May eliminate fish community (complete dry dredging only). Possible impacts from containment area discharge. Possible impacts from dredged material disposal. Interference with recreation or other uses during dredging.
Dyes	Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth. Dyes remain in solution until washed out of system.	Light limit on algal growth without high turbidity or great depth. May achieve some control of rooted plants as well. Produces appealing color.	May not control surface bloom-forming species. May cause thermal stratification in shallow ponds. May facilitate anoxia at sediment interface with water.
Biological controls	Manipulation of biological components of system to achieve grazing control over algae. Typically involves alteration of fish community to promote growth of large herbivorous zooplankton. Viruses or other pathogens have been used as well.	May increase water clarity by changes in algal biomass or cell size distribution without reduction of nutrient levels. Can convert unwanted biomass into desirable form (fish). Harnesses natural processes to produce desired conditions.	May involve introduction of exotic species. Effects may not be controllable or lasting. May foster shifts in algal composition to even less desirable forms.
Nutrient input reduction	Includes wide range of watershed activities intended to eliminate nutrient sources or reduce delivery to lake. Includes erosion control measures, agricultural and storm water BMP's, waste water trtmt, and land planning.	Acts against the source of algal nutrition. Creates sustainable limitation on algal growth. May control delivery of other unwanted pollutants to lake.	May involve considerable lag time before improvement observed. Reduction of overall system fertility may impact fisheries. May cause shift in nutrient ratios which favor less desirable species.

Of the techniques to reduce internal loading, hypolimnetic withdrawal is not a physical possibility in this natural chain of lakes, and there is no available source of high-quality water for dilution or flushing. Dredging is technically and economically infeasible in the deeper portions of the lake where the sediments influencing internal loading are located. Circulation may be applicable, but only to the extent that it addresses oxygen problems, and will therefore be considered as part of the aeration approach. This leaves only aeration and inactivation as viable approaches to combating internal phosphorus loading.

Regarding circulation, one or more Elk residents has suggested that widening the interface between the north and south basins might be beneficial. The historic interface between these two basins has been reduced by intentional filling west of the now abandoned fort on the causeway (which was once an island). Under current conditions, however, the limited interface between the north and south basins makes improvement of the north basin possible without extensive action in the south basin. More mixing between these basins is not advised at this time, as the south basin is still receiving a substantial nutrient load from its watershed. Movement of a greater portion of that load into the north basin would be undesirable.

C1. Aeration

Aeration in the Lake Elckie system could provide major improvements in water clarity and coldwater fish habitat. By keeping the hypolimnion from becoming anoxic during stratification, aeration should minimize the release of phosphorus from deep bottom sediments and increase the volume of water suitable for habitation by trout and other fish. The dissolved levels of a number of other contaminants (e.g., hydrogen sulfide, metals, ammonium) are likely to decrease markedly in aerated waters as well. However, the impact of aeration on phosphorus levels depends upon a variety of factors.

Aeration has been successful in reducing available phosphorus in many lakes, but not to the extent or duration expected from theory. In a review of a number of examples, Cooke et al. (1993) note that available phosphorus tends to decline one-third to two-thirds during aeration, but quickly rises to pre-aeration levels when treatment is ceased. One way to improve and extend results is to add a phosphorus binder such as aluminum or iron to the process; aeration promotes binding activity and bound phosphorus does not necessarily become available after aeration ceases.

Sedimentation of previously available phosphorus in a Canadian lake increased by almost an order of magnitude after aeration with the addition of iron to an iron-phosphorus ratio of 10 to 1 (McQueen et al. 1986), and the combination of iron and oxygen was similarly successful in a Minnesota Reservoir (Walker et al. 1989). The process of nutrient inactivation is covered separately in this analysis, but where binders are already present it appears that aeration can improve their activity. Where binders are scarce, there may be a need to add them. Limited information for Lake Elckie suggests that there is insufficient iron naturally present; further investigation is needed to verify this supposition.

There are several types of aeration, but not all are appropriate for Lake Elckie. Surface aerators will do little to reduce the hypolimnetic oxygen deficit. Systems which bring deep water to the surface can be inexpensive, but unless enough water is brought up to prevent anoxia, the quality of that water which is brought up may cause greater deterioration of surface conditions. Such systems could be useful here only if a return mechanism was added to return oxygenated water to the original collection depth.

Systems which pump air into the bottom waters without destratifying the lake could be very useful, but tend to be more expensive. Systems which pump surface water to the bottom could also be useful, but a careful balance must be struck between pumping enough water to sufficiently aerate the hypolimnion and avoiding destratification prior to complete treatment. Aerators which use diffusers to destratify a lake could be effective in Lake Elckie, but might require the addition of phosphorus inactivators (alum, iron, or calcium) to reduce internal phosphorus cycling. Additionally, destratification is generally undesirable for the north and south basins; fishery impacts could be significant and the energy requirement could make such destratification very expensive.

Timing of aeration is also important. Aeration is possible at any time of year, but the most critical time to have oxygen in the bottom waters is during the summer, especially if the lake is stratified. Aeration at any other time of year must be sufficient to oxidize the bottom sediments to the extent that the oxygen demand in the following summer is greatly reduced. This has generally not been the case in recorded aeration experience, and the inputs to Lake Elckie suggest that such an approach will require at least several years to create the desired impact, if it works. Waiting several years to see improvement after a substantial investment may be publicly intolerable, especially after having waited some time for the sanitary sewer renovation to result in lake improvements. Any first effort at aeration should probably focus on marked improvement of summer conditions within the year of implementation.

For Lake Elckie, an aeration system must deliver enough oxygen to at least keep the hypolimnion from going anoxic and maintain an oxygen level of 5 mg/l if a viable deep water fishery is to be maintained. For the north basin, this means adding oxygen at a rate of at least 80 kg/d and preferably 400 kg/d. To completely counter the oxygen demand, about 860 kg/d would be needed. Corresponding values for the south basin are 900, 4,550 and 10,000 kg/d. The west basin has minimal hypolimnetic volume, but aeration of the entire basin appears necessary to counteract the internal input of phosphorus. For the west basin, the needed oxygen input values would be at least 200, 1,000, and 2,100 kg/d to maintain concentrations of 1, 5, and 11 mg/l. There is a second estimate of ODR that more than triples these estimates, but it seems less appropriate since atmospheric air inputs also affect most of the volume of this basin.

The amount of air necessary to provide the desired oxygenation is a function of water depth and transfer efficiency. Table IV-1 calculates the minimum air needs.

Table IV-1. Estimated Minimum Air Needs

	North Basin		South Basin		West Basin	
Final Oxygen Conc. (mg/l)	**Oxygen Need** (kg/d)	**Air Need** (m^3/d)	**Oxygen Need** (kg/d)	**Air Need** (m^3/d)	**Oxygen Need** (kg/d)	**Air Need** (m^3/d)
1	80	900	900	3,800	200	6,700
5	400	4,500	4,550	19,000	1,000	33,200
11	860	9,600	10,000	41,500	2,100	70,000

For electrically powered aerators, blowers would have to be sized accordingly (one can get roughly 7.8 m^3/h/hp). Where the need exceeds reasonable blower power, multiple units would be needed. As each basin has at least two major depressions, it is assumed that at least two units would be used per basin to maximize distribution of oxygen. This is not essential, but seems appropriate. More units could be used as necessary, but the depth at which units are installed will affect maximum vertical distance of air-water contact, which will determine oxygen transfer efficiency and the amount of air needed to supply the required oxygen. The longer the travel path for air, the greater the transfer of oxygen to water, so deeper installations are preferable.

An additional benefit from multiple units is enhanced horizontal distribution of oxygen. Input to a large basin from a single unit may be sufficient in total input, but the distribution of the oxygen will not be uniform. Use of multiple units will not ensure even distribution, but will provide more even distribution than a single unit.

Regarding Lake Elckie, there are four distinct systems with applicability. The first is the "partial air-lift system," in which air is pumped into a submerged chamber where exchange of oxygen is made with deeper waters pulled into the chamber by the suction created by air movement (see Figure IV-1, page 34). The newly oxygenated waters are released back into the hypolimnion without destratification. This system is commercially available as the Stratiflox unit or Limno apparatus (two similar brands). A shoreline site for a housed compressor would be needed, but the aeration unit itself would be submerged and would not interfere with pond use or aesthetics. Capital outlay would be from $80,000 to $120,000 per unit, depending on size, with total capital cost depending on how many units are installed. A single unit should deliver oxygen at a rate from about 200 kg/d to 500 kg/d. Operational costs would include mainly electricity and be dependent on the rate of airflow needed. An additional cost of $2,000 to $4,000 per summer season per unit should be assumed in maintenance costs.

These units would be appropriate for the north and south basins. There is some concern, however, that the separate depletion of oxygen observed in the south basin around the thermocline before the hypolimnion has gone completely anoxic could cause some internal recycling independent of expected sediment release of phosphorus. The oxygen depletion at the thermocline appears related to the accumulation and decomposition of organic particles at this density boundary, a known phenomenon in similar lakes. If this activity is significant, aeration of the hypolimnion might not prevent recycling of phosphorus adequate to fuel algal blooms in the surface waters. More monitoring is needed in the south basin before an expensive aeration system could be comfortably recommended.

Where destratification is not an issue, as with the west basin at any time or the north and south basins during autumn, winter, or spring, a diffuser-type system (see Figure IV-1) could be applied. This includes a wide variety of commercially available systems, of which the D-flox system known locally is an example. Air is placed near the bottom of the lake through tubing and dispensed through one of a variety of nozzles, the design of which tends to separate the available brands. Air and water rise in response to the input, with air transferred up to the point where it reaches the lake surface. Water is also artificially circulated in this manner, aiding distribution of oxygenated waters and entraining some particles with the intent of better oxidation. Upon settling, well-oxygenated particles can bury the more oxygen-demanding particles still on the bottom, limiting future expression of oxygen demand.

Figure IV-1. Schematic Diagram of Aeration Approaches

This process is normally used in shallow lakes, but could be applied in deeper situations during non-stratified time periods or where destratification is desired or not a concern. Use of such a system in the north or south basins would raise the overall temperature of the lake slightly, but would reduce the average temperature at the lake surface. This could have negative impacts on fish populations and may discourage some swimmers, but it is not clear that there would be any major impacts of this sort in Lake Elckie now. Of greater concern is the potential for greater nutrient availability if the lake is completely circulated but phosphorus release from sediments is not greatly suppressed. The potential scarcity of iron or other phosphorus binders in Lake Elckie lends additional concern about this approach. If this type of system is used, iron levels must be sufficient to bind all potentially available phosphorus. Running a diffuser-type system periodically during the summer without destratifying the north or south basins may be possible and yet put in enough oxygen during several days to maintain oxygen levels above 1 mg/l. This is an experimental approach and would require careful monitoring of oxygen and nutrient levels with manual adjustment of airflow. Some demonstration of effectiveness would be desirable before expending substantial funds on such a system in basins as large as the north and south basins of Lake Elckie.

The cost for diffusion aeration systems can vary considerably, but an estimate of \$300 to \$350 per m^3/h of air to be supplied is reasonable, with some escalation of costs for smaller installations. Operating costs depend on power usage, at a range of about \$0.05 to \$0.15 per kWh. For the north basin, the capital cost of maintaining an oxygen level of 5 mg/l would be about \$56,000 to \$66,000, with an operating cost similar to that described for the partial lift system (non-destratifying approach, about \$2,000 to \$4,000 per season). Of course, this type of system could be run all year long at no additional capital cost and a roughly proportional operating cost, but there has been no clear demonstration that this will reduce future summer oxygen deficit in a deep lake.

The third applicable approach involves a process called layer aeration (Kortmann 1988). It works like the complete water lift system, but aerated water is used to form an oxygenated layer which acts as a barrier to the passage of phosphorus, reduced metals, and related contaminants. The layer is stable as a consequence of thermally mediated differences in density, and resists the passage of phosphorus across the newly created layer to the epilimnion. A layer can similarly be created near the bottom, to limit phosphorus release from the sediments and possibly limit oxygen depletion in much of the overlying hypolimnion. Less of the anoxic portion of the lake would be treated and converted to usable habitat for fish and zooplankton, but such habitat could increase markedly and phosphorus cycling could be reduced.

At least one area within the lake would need to be set aside as a surface aeration location (this system mechanically mixes and aerates the water and places it back into the target area), but movement of waters would be through subsurface pipes which should not interfere with lake uses. The capital outlay would be about \$50,000 to \$75,000 per unit, with operational costs slightly less than the partial lift system, since less water is treated. There could be some objectionable odor associated with the surface aeration area, especially if the system is not run continuously. This system’s main advantage is in lowering the cost to achieve a limit on phosphorus passage into the upper water layers.

The layer air system would be appropriate mainly in the south basin, where the large volume of hypolimnetic water creates a large cost for even the minimum necessary increase in oxygen level for the whole volume. The object would be to aerate either the area right around the thermocline or very near the bottom. The difficulty of adequately aerating at the thermocline will be increased due to apparently high oxygen demand created by settled organic particles, and application near the bottom may not prevent the anoxic layer at the thermocline from forming. Additional data for the temporal progression of the oxygen deficit near the thermocline in the south basin would be necessary to completely evaluate this option.

The fourth and final aeration system is rather different than the others, relying on the pumping of oxygen rich surface waters into the bottom layer to offset the oxygen deficit. This can be accomplished electrically, but at lower efficiency than pumping air. A Finnish firm, however, has developed a wind-driven mechanism for pumping water from the surface to the bottom (called “WiWa” for wind and water). The lower capital cost (about $26,000 per unit) and minimal operating cost (maintenance only) are attractive, but there is only one installation known for this device, and monitoring data are not readily available. This system appears to have worked well in its initial trial, but the capacity of the device over the range of possible lake conditions is not clear.

Information from the inventor and supplier indicates a typical movement of 100 l/s per unit from the surface to depths almost as great as would be necessary in the south basin. Assuming complete mixing in the hypolimnion and no loss of oxygen due to rising warmer waters that have been put into colder hypolimnetic waters, it would take 1 m^3 of well-oxygenated upper water (normally at >10 mg/l of oxygen) to raise the oxygen level of 10 m^3 of anoxic bottom water by 1 mg/l/d. Since the ODR on a volumetric rate is around 0.25 mg/l/day as an average for the north and south basins, that 10 percent water replacement would have to be supplied every four days to maintain the 1 mg/l oxygen level. For the north basin, this amounts to 473 l/s, or five units operating simultaneously and continuously; for the south basin, it correlates to 6,626 l/s and 66 units. To increase the oxygen to 5 mg/l, the needs would be multiplied by five, which is financially and physically unattractive.

In discussions with the supplier, however, it was suggested that the oxygen-rich water might not mix evenly and might stay near the bottom where it would have the most impact. How this could occur is not clear given the thermal gradient created by pumping the warmer water down to the bottom, but providing some form of dispersal mechanism to hasten mixing near the bottom might be possible. As this will not change the oxygen demand, however, this would at least theoretically not alter the number of units necessary. Unreliable wind conditions also represent a potential barrier to consistent success for this approach. This option should only be pursued after demonstration of its potential effectiveness.

An appropriate aeration system could make a marked improvement in Lake Elckie conditions, but practical experience has shown that effects are not uniform or reliably consistent within and among aquatic systems. Zones of minimal interaction will often occur, resulting in at least localized anoxia and possible phosphorus release. Downtime on aerators, especially if wind power is used, will cause temporal fluctuations in oxygen content. The layer air and partial lift hypolimnetic aeration systems may allow a band of anoxic water to persist near the top of the metalimnion, allowing nutrient cycling and supply to the epilimnion and discouraging vertical migration by fish and zooplankton. Even under oxic conditions, there is some phosphorus release from the sediments.

There is a remote possibility of inducing “gas bubble disease” in fish through supersaturation of nitrogen (not just oxygen is transferred if air is used). Negative impacts of nitrogen could be overcome by using pure oxygen in a partial air lift system, but operational costs would increase about twofold.

Despite potential shortcomings, however, aeration remains a valuable tool for reclaiming Lake Elckie and appears immediately applicable to the north basin with potentially excellent results. Use in the south and west basins would also be beneficial, but whether water clarity goals can now be achieved in those basins with aeration alone is not clear.

C2. Phosphorus Inactivation

The theory of phosphorus inactivation is fairly simple: A chemical that is only marginally soluble but has a high affinity for phosphorus is introduced to the water column and allowed to bind existing phosphorus and precipitate out. The bonus in this treatment is that the precipitating flocculent forms a layer on the bottom sediment that can retard future phosphorus release. This layer may sink into the soft muck in the deep part of Lake Elckie, but the binding of phosphorus should still be effective (Cooke et al. 1993). Inactivating phosphorus is also possible, at least temporarily, by binding it in organic matter. This is what the algal blooms are doing, with unwelcome results at the lake surface. Subsurface substrates for attached growths could be supplied, however, to localize phosphorus uptake and reduce available phosphorus in other areas of the lake.

Improved water clarity is almost certain from chemical phosphorus inactivation, but will be temporary if external inputs are not sufficiently controlled. Control of algal growths should be achieved if those growths are dependent on internal sources of phosphorus. Reduced oxygen demand is also expected, but the hypolimnion is still likely to be largely unsuitable for fish without supplementary oxygen inputs.

Alum, or aluminum sulfate, has been the most widely used chemical for this treatment because it binds phosphorus well under a wide range of conditions. Although alum is not very soluble, concentrations in excess of 50 μ/l may cause toxicity for aquatic fauna and the solubility increases with decreasing pH. A minimum pH of 6.0 virtually ensures that the 50 μ/l limit will not be reached, but alum addition can reduce the pH well below this level in poorly buffered waters. In such cases, sodium aluminate, a more pH neutral chemical, has been used with success (Cooke et al. 1993). Other chemicals that have been successfully used include calcium hydroxide, calcium carbonate, ferric sulfate, and ferric chloride; the former two tend to raise the pH and the latter two lower it. Iron compounds are particularly appealing for phosphorus inactivation, since iron is one of the most abundant elements in the crust of the earth and has almost no toxic effects. Iron provides natural inactivation where it is abundant and the oxygen supply is sufficient.

Phosphorus inactivation has received increasing attention over the last decade as long-lasting results have been demonstrated in multiple projects, especially those using alum (Cooke et al. 1993; Connor and Martin 1989a, 1985b; Connor 1992; Smeltzer 1990, 1993). Phosphorus decreases of about 65 percent in Kezar Lake in New Hampshire and Lake Morey in Vermont are examples of successful aluminum-based phosphorus inactivation projects in New England. Annabessacook Lake in Maine suffered from algal blooms linked to internal phosphorus loading, but after treatment cyanobacteria blooms were eliminated and conditions have remained much improved to date (15 years). Some decline in recent years suggests that another treatment may be needed soon (Monagle 1992). Similarly impressive results have been obtained in two other Maine Lakes using two aluminum compounds which buffer each other to minimize pH fluctuations (Connor and Martin 1989a). From personal experience, treatment of Hamblin Pond in Massachusetts in 1995 has resulted in a summer water clarity change from 1 to 6 m for two years.

Phosphorus inactivation has also been successful in some shallow lakes (Welch et al. 1988, Gibbons 1992), but has been unsuccessful in cases where the external loads have not been controlled before inactivation (Barko et al. 1990, Tyning 1992). Successful dose rates have ranged from 18 to 44 g Al/m^2 with pH levels remaining above 6.0. Jar tests are used to evaluate the appropriate dose and optimal mixture of aluminum sulfate and sodium aluminate; the former decreases pH but is less expensive than the latter. Application of the chemical to deep lakes is usually done near the thermocline depth (even before stratification), providing a precautionary refuge for fish and zooplankton which could be affected by dissolved aluminum. Application methods include modified harvesting equipment and specially designed barges made for this purpose.

Success has been achieved with calcium (Murphy et al. 1988, Babin et al. 1989) and iron (Walker et al. 1989) salts, but clearly aluminum provides the greatest long-term binding potential for phosphorus inactivation (Harper 1992). Calcium would seem to be most desirable in low pH lakes, while iron seems to be most useful in conjunction with aeration systems. Aluminum salts can be used successfully in any of these cases, however, and would be the chemical of choice unless toxicity becomes a problem. For Lake Elckie, where aeration of the hypolimnion is desired, iron would also be suitable and should be less expensive than aluminum.

Cost for nutrient inactivation projects varied substantially in the early years of this technique, but have stabilized in recent years through development of application means and chemical supply markets. A cost of $1,500 to $2,000 per hectare treated is expected for an aluminum sulfate/sodium aluminate treatment. Given the substantial alkalinity in Lake Elckie and the greater expense of sodium aluminate, only aluminum sulfate may be needed at Lake Elckie. This would reduce the cost to about $1,000/ha. Iron chloride could be applied for as little as $500/ha, but this approach is only viable if the hypolimnion is aerated.

The combination of aeration and addition of a phosphorus inactivator is an attractive option for Lake Elckie, especially the north basin. This combination could be made to work in the south and west basins as well, but effects may be of shorter duration if external inputs are still high; some additional monitoring should be conducted before implementing such a process on a large scale there. Evaluating hypolimnetic iron levels in the north basin would also be desirable, but it seems apparent that these levels are currently insufficient in that basin (and probably the other two as well). Aeration with iron addition also has great applicability for limiting the impact of loads from the Elk River and Lake Sunowo, and could be implemented on a fairly small scale to address late spring and summer loads if they prove significant in overall lake condition.

In theory, iron binds phosphorus in the presence of oxygen at almost a 1-to-1 ratio on a weight-to-weight basis. In practice, the efficiency of binding is not so high, and at least five times as much iron is needed, with some cases requiring 15 times as much iron. Assuming a target iron-phosphorus ratio of 10 to 1, 11,250 kg of iron could bind up the entire summer release of phosphorus from the sediments of the north basin. We do not know how much iron is currently available in the hypolimnion to react upon oxygenation, but assuming that there was virtually none, the iron should cost about $0.60/kg, or a total of $6,750. A delivery system to add iron to the aeration system might cost $3,000 to $4,000 more, so for under $11,000 the inactivation of phosphorus during aeration could be much enhanced. Some of this iron will be flushed from the system over time, but a one-time addition over a single summer should be adequate to control phosphorus release with aeration only until new phosphorus inputs from the watershed push the iron-to-phosphorus ratio below about 5 to 1.

The same approach in the south basin would cost about $35,000, and in the west basin from $24,000 to $60,000 depending on how fast the iron is flushed from the system in this basin with low detention time. Since the importance of external inputs to the south basin may still be critical to summer conditions and the flow of phosphorus from the south basin to the west basin is substantial, simply inactivating the internally recycled phosphorus may not be sufficient to reduce phosphorus enough to alter water clarity in a major way in these two basins. More monitoring is needed to make a more informed decision, especially since the companion aeration program would be quite expensive.

Assuming that iron inputs to the system are too low to inactivate the incoming phosphorus load, which appears to be the case from limited data for the Elk River and Lake Sunowo (including the fish hatchery), the use of a diffuser aeration system with iron injection at the inlet of each of these water/nutrient sources could inactivate inputs inexpensively and limit additional loading, especially during the critical late spring and summer period. Assuming the late spring/summer inflow from Lake Sunowo averages 500 l/s with an average phosphorus level of 0.15 mg/l, treating for a five-month period would require slightly less than 1,000 kg of iron at a cost of about $6,000, exclusive of a delivery system. Dripping an iron solution into the outlets would be inexpensive, and could be enhanced by a single aeration diffuser at each of two locations for perhaps $5,000.

The same approach for the Elk River would require more iron, given a flow of about 2 m^3/s and a phosphorus concentration as high as 0.4 mg/l. A cost of about $62,000 is suggested for the five-month period, exclusive of a delivery system, which might cost another $10,000 to $15,000. More monitoring data should be gathered for the Elk River first, but it would be worth trying a pilot test of iron addition to the Lake Sunowo discharge to the north basin, possibly with a temporary mixing system of limited cost.

The use of substrates that promote biological growths that bind up phosphorus is essentially a biological treatment method, but it is also a nutrient inactivation approach. Many types of biological treatment systems have been developed for processing wastewater from different industries or from municipal sewage, and application of this technique to the lake environment is a logical extension of this approach. In essence, a portion of the lake is being used as a biological treatment reactor, with attached biota providing the treatment and remaining in a confined area of the lake. This should, in theory, improve conditions elsewhere in the lake.

Some success has been achieved with the “bioplate” method elsewhere in Poland (Kudelska 1992, Gromadzki 1997), and the process is relatively inexpensive over multiple years as a function of bioplate durability. Removal of phosphorus is enhanced by higher oxygen levels, for reasons of both biological metabolism and reaction with any available iron, so aerators are normally installed near the substrates. Removal of more than 80 percent of the total phosphorus has been recorded in several lakes during operation of this system, although these lakes had much higher initial concentrations of phosphorus than does Lake Elckie.

Use of this approach in the north or south basins as the sole means of reducing phosphorus availability would seem to require destratification, as hypolimnetic conditions are not conducive to the types of growths desired. Whether use of this system at other times of the year would yield adequate results in the following summer is not clear. Costs, at about $50 per bioplate plus aerator expenses, would be substantial for these large volumes of water. Some improvement would be expected, but whether certain water quality objectives would be met is uncertain.

Use of bioplates or similar devices to attempt to minimize the movement of phosphorus from either the Elk River or Lake Sunowo into Lake Elckie has merit and may provide a viable supplement to aeration or chemical phosphorus inactivation. Cost is a function of the number of plates used and aerator costs. For installations at the north end of the north basin to handle inputs from Lake Sunowo and the fish hatchery, or at the inlet from the Elk River, a cost of $20,000 to $40,000 is expected. This would include a shallow diffused air input system and 300 to 600 substrates at each location. An annual maintenance cost of $1,000 should be assumed.

One other approach to limiting phosphorus availability should be mentioned here. It is somewhat of a hybrid between inactivation and aeration and involves the addition of an oxidizing agent directly to the bottom sediments. Developed by Ripl in Germany, this approach typically employs Riplox, a calcium nitrate solution which provides calcium to bind with P and nitrate to provide oxygen for satisfaction of sediment oxygen demand. Whether this method would be either technically or economically feasible in Lake Elckie is not clear, and the use of better known aeration and/or inactivation techniques appears preferable.

D. Improving Aesthetics

Aesthetics are to some degree a subjective matter of opinion, but most people would agree on the need to minimize erosion scars and debris accumulations along the shoreline, and to prevent obnoxious odors typically associated with decaying algal blooms and hydrogen sulfide production. Reaction to higher water clarity is also usually positive, and a vegetated shoreline is often preferred to a visibly structurally stabilized one. Issues of water clarity and odor are addressed in the section on improving water clarity, and the town has used structural shoreline stabilization only where apparently necessary, so these issues require no major discussion here.

Regarding erosion scars, these seem associated with points of frequent access where the slopes are steep and the soil sandy. Preventing access is one solution, but would seem contrary to the commendable policy toward maximizing shoreline access for the general public. Alternatives range from concrete structural supports and platforms in erosion-prone access areas to vegetative stabilization with some maintenance to ensure continued function. Either can be done in an aesthetic manner, at a cost of about $100 to $200 per linear meter of shoreline or square meter of total area treated.

The issue of debris is a common one and not completely solvable in an urban area. The appearance of such refuse in the lake is almost unavoidable, although it can be kept to a minimum by behavioral controls and civic pride, but those seem apparent already in Elk. What is probably most needed is a periodic clean-up day. Though this is beyond the scientific scope of this report, it might be suggested that an annual clean-up day be instituted, followed by a lake festival. The ideal time would be late enough in the spring to allow people to come in contact with the water without serious chill, while early enough to pre-date any major use of the lake for swimming or related pursuits. Late May or early June would seem to be the best time frame.

The use of a lake festival could serve a variety of purposes, starting with a clean-up day and progressing to an environmental information fair, perhaps with booths along the promenade on the east side of the north basin. The event, best scheduled over a weekend, could then, progress to simple fun activities related to water such as boat races or a fishing derby, whatever the Town of Elk wishes. It could eventually become a draw for tourism.

E. Improving Fishing

While only limited information about the fishery is available, it is apparent from the lack of oxygen in the hypolimnion and limited submergent vegetation that the habitat is suboptimal. Fish production is high, but the quality of the fishery seems low. There are reportedly many cyprinid fishes and fewer individuals of predatory species (piscivores) such as pike (*Esox*) and large perch (*Perca*). Populations of trout or other desirable species are apparently not substantial in Lake Elckie. The key to a rejuvenated fishery is additional predatory fish and regulations to limit their removal by fisherman until populations become well established with strong year classes through reproductive ages.

The first step involves improving the hypolimnetic oxygen situation, which is addressed under the section on improving water clarity. The second step would involve establishing more submergent vegetation in the pond, preferably at a coverage of about 25 to 40 percent over the area <15 ft deep. Such vegetation will probably establish itself naturally if water clarity increases, but there is some merit to planting or seeding areas with preferred vegetation such as pondweeds (*Potamogeton*) native to the area. These plants rarely achieve nuisance densities and provide food and cover for both fish and waterfowl.

A third step, but one which could begin at any time, would involve stocking predator fish to enhance the populations of those species. A prey-to-predator ratio for adult fish of about 6 to 1 would be desirable. The current ratio is unknown, but is likely to be much higher. A stocking rate of about 250 predators per hectare, stocked as fingerlings (year old fish) or slightly larger fish, would seem appropriate. This action may have to wait for better water quality in the case of trout, but could begin immediately for some other species.

Specimens of predator species should not be removed until the population has achieved some stability, which could take five years or more. This is difficult to enforce and not popular with many fishermen, but most will understand the rationale for such action if explained clearly. Working through the Polish Fishing Association would be advisable.

To establish viable populations and restore balance to the fishery, predators must be allowed to grow and reproduce. The fishing will then be much better, and well worth the wait. This does not mean there can be no fishing in the meantime, but all predator species caught should be returned to the water unharmed. Additionally, all prey species should be kept and not released back into the lake, although this action almost never is sufficient by itself to control prey species such as many of the cyprinids. Alteration of some regulations and enforcement activities are likely to be necessary.

F. Assessing Conditions

Monitoring is essential before, during, and after lake restoration. It provides the necessary information for assessing the feasibility of management options, allows tracking of progress, and facilitates detection of new or recurring threats. This assessment of management options was made possible by the work of many people and requires many assumptions and reliance on experience elsewhere because the database was limited. Where so much money may be spent on restoration, monitoring is a small portion of the budget and is money well spent.

Additional information on the input of phosphorus and nitrogen to Lake Elckie and the resultant concentrations at key points would be useful both in determining the appropriate next steps lake management and in tracking the results of management efforts. Data on in-lake and incoming iron levels would be especially helpful in determining the need and utility of nutrient inactivation in association with aeration. Periodic checks on temperature, dissolved oxygen, and water clarity are also needed to document progress and verify estimates of oxygen deficit and internal phosphorus release and utilization. Observations on the types of algae present and any discernible production of hydrogen sulfide would also be useful.

It is suggested that the six previously monitored in-lake sites be sampled at the top and bottom, with a complete T/DO profile and measurement of water clarity, with analysis of soluble and total phosphorus, ammonium, nitrate and total Kjeldahl nitrogen, and dissolved iron. Sampling should be conducted over the summer (June-September), in December, in late February, and from May through September in 1998. Samples should also be collected at the connection between the south and west basins in June-August to evaluate summer transport of phosphorus into the west basin.

The discharge from Lake Sunowo to the north basin and from the Elk River to the south basin should be sampled monthly throughout the 15-month period to gain a better perspective on these potentially critical inputs. Additionally, three samplings of at least five storm water drainage systems should be conducted to gain insight into the actual quality of urban runoff in this watershed and the need for further storm water quality renovation.

This program would involve analyses of up to 171 samples at a cost of about $70 per set of analyses (on each sample), for a cost of about $12,000. Sampling labor and transportation, if not provided locally by volunteers, could cost an additional $2,500. If the work was done by volunteers, some equipment would be needed at a cost about equal to the labor cost, but that equipment (T/DO meter, Secchi disk, sampling gear) would then be available for future monitoring. Much monitoring is now carried out successfully in the United States by volunteers, enhancing public education and cost savings.

Some additional investigative sampling and monitoring associated with actual management actions should also be planned. For example, it would be desirable to evaluate the mixing of the Elk River inflow in the south basin by using a dye test, and it would also be helpful to sample phosphorus near the thermocline during periods of stratification in the north and south basins. A budget of $3,000 is suggested to cover this supplementary sampling during the upcoming 15-month period.

Monitoring the results of aeration is also essential. This would involve temperature and dissolved oxygen measurement at about 2-m intervals at the nodes of a grid pattern covering the north basin (about 20 sites). This requires only a portable dissolved oxygen meter, which can be purchased for about $1,500 and maintained for $200 per year (note that purchase of a T/DO meter was also suggested for the routine monitoring component). Measures of total and dissolved phosphorus at surface, metalimnetic and bottom depths at about 10 horizontal points would also be insightful, and a cost of $7,000 is suggested for all sampling equipment and analysis during the initial treatment year. During any addition of phosphorus inactivators, pH should be monitored at least weekly in the vicinity of the input point, to ensure no adverse fluctuations in pH. A colorimetric pH kit is sufficient for this task, and will cost less than $100.

Monitoring is often cut from management programs when funds are scarce, since it does not directly contribute to the improvement of the lake being managed. However, many lake management programs have failed because there was inadequate data to allow evaluation of progress and adjustment of actions to achieve the desired results. Trial and error approaches are sometimes necessary in lake management, but the need for guesswork and potentially wasted expenditures can be minimized by proper monitoring. Furthermore, larger lake programs within governmental institutions have been cut due to the failure to document results, even where results are apparent. As lake management in Poland is in its early stages, careful documentation of results will be of great future benefit.

SECTION V
RECOMMENDED MANAGEMENT PROGRAM

A. Primary Management Actions

Monitoring program. While typically the last element of a management program, the monitoring plan is placed first here because it requires information that is critical to immediate future planning. Knowledge of the iron content of the lake and major tributaries is essential for determining the degree to which iron addition may be necessary in association with aeration to inactivate phosphorus. Additional data on phosphorus and nitrogen inputs and in-lake water clarity and temperature-dissolved oxygen profiles are also needed to verify estimates made in this assessment. Continuation of the monitoring program outlined in the previous section for at least the next 15 months is strongly recommended and will cost about $18,000.

Additionally, monitoring the results of the proposed in-lake management actions for the north basin is essential to evaluate performance and adjust the management strategy for maximum results. Measuring temperature and dissolved oxygen profiles at 20 sites and testing for total and dissolved phosphorus at three depths at 10 sites are suggested on a scheduled basis. Water clarity and pH measurements at selected locations should also be included. Equipment and lab analyses will cost up to $9,000. The additional labor cost for this effort could be substantial, but it is strongly recommended that a volunteer monitoring program be set up for the lake. Aside from the cost savings in actual sample collection, involvement by local parties is beneficial in many other ways, and is quite consistent with the “Elk—Ecological Town” theme. More detail on this monitoring plan are included in Annex D.

Completion of sanitary sewer improvements. The upgrading and relocation of the wastewater collection and treatment system is the single biggest improvement made in the watershed, and despite the lack of desired clarity in the lake, this change has had a major effect on reducing pollutant loading to the lake. If not for this effort, we would not be at the point of discussing further management needs to meet water clarity goals. This work should be continued and completed, and working with upstream communities may be necessary to encourage improvements in the Elk River and possibly Lake Sunowo.

Storm water quality management. Fecal coliform bacteria, nutrients, and other contaminants from urban runoff routed to the lake or the Elk River by storm water drainage systems create a substantial threat. They threaten the health of people coming into contact with the lake water, cause unaesthetic conditions inconsistent with the desired quality of the lake, and contribute a distinct though not major, portion of the nutrient load that promotes algal blooms. The installation of grease and grit traps should proceed, with consideration given to additional storm water quality improvement if indicated by monitoring the results. Even if storm water runoff from urban areas is not a major source of future nutrients, the timing and location of inputs will have distinct localized impacts along the shoreline that will affect public perception of the lake. Continued attention to the storm water drainage system is warranted.

Agricultural runoff can also pose a threat to the lake, but is not an extreme hazard. Establishment and maintenance of buffer strips of 30 to 75 m width between active agricultural areas and the lake or its tributaries are desirable, with dense cover crops in those buffer areas and no piping or ditching to promote direct runoff to the lake or its tributary streams.

Hypolimnetic aeration/supplemental phosphorus inactivation. Aeration of the hypolimnion of the north basin appears to be justified and could result in a major improvement of water clarity, fish habitat, and general ecological health. Late spring and summer addition of oxygen to the bottom waters in a way that does not break stratification appears to be the best approach, but may require the addition of a phosphorus binder such as iron to maximize effectiveness and longevity of results. Additional aeration by diffuser units during seasons when the lake is not stratified would provide more economical improvement during those periods and could reduce the long-term oxygen deficit.

The equipment to be used must be able to deliver at least 400 kg of oxygen per day and to increase the input to 800 kg per day if so desired without destratifying the lake during the summer. The oxygen level throughout the hypolimnion should be maintained above 1 mg/l, with an expected average close to 5 mg/l. Long-term reduction of oxygen deficit should be facilitated, but not at the expense of initial and continued improvement of hypolimnetic conditions. Measurable improvement should be expected during the first summer of operation.

If properly implemented, this approach will reduce the overall phosphorus load to the upper waters of the north basin to a point below the critical load and possibly approaching the permissible loading level. However, this depends primarily on the quantity of inputs from Lake Sunowo during the summer. Resultant hypolimnetic oxygen levels should be raised to near 5 mg/l, and water clarity during the summer would exceed 2 m and could approach 3 m. Hydrogen sulfide would not be produced and ammonium would not accumulate in the bottom waters. Most, if not all, of the hypolimnion would be suitable for fish habitation.

Multiple equipment arrangements could be used to achieve the above performance criteria. The least expensive option with the potential to provide the desired summer conditions would involve placement of a single partial lift (non-destratifying) system in the northern sub-basin of the north basin. At $100,000 in capital cost and $4,000 in summer operating expense, the hypolimnion should be kept sufficiently oxygenated, although even distribution of oxygen is not expected with a single unit. The addition of iron is recommended unless new testing indicates that the iron concentration in the hypolimnion is at least 10 times the phosphorus level, which based on past data would have to be about 3.5 mg/l of iron. The use of ferric chloride or ferric sulfate should be suitable, and a cost of up to $11,000 is envisioned for the first year. Subsequent need for the iron addition is uncertain and should be determined through monitoring.

A more comprehensive arrangement would involve use of a partial lift unit in the northern sub-basin of the north basin, with supplementary diffuser systems around it and separately in the southern sub-basin of the north basin. Each sub-basin would have its own compressor unit. The partial lift system would operate during summer and should be sufficient to supply the oxygen necessary to the whole basin. The diffuser systems could be run during autumn, winter, and spring, and in support of the partial lift system in small bursts as needed during summer. Iron injection could be added to each sub-basin as needed, based on measurement of available iron.

This system provides the greatest flexibility of operation and should be able to handle all possible circumstances in the north basin. Total cost could approach $200,000, and operational costs could approach $20,000 per year. Other equipment arrangements are also possible and proposals should be considered if they can meet the above performance standards. Key aspects of the aeration of the north basin are summarized in Annex D.

The use of aeration in the south basin (by non-destratifying equipment) and the west basin (by diffusion aerators that destratify) cannot be strongly recommended on a basinwide level now due to a lack of clear indication of the importance of internal recycling in those basins and the amount of iron that might be available for natural inactivation. Likely the internal recycling is important in both basins and the naturally available iron is insufficient to bind the available phosphorus, but this would suggest a large cost for controlling phosphorus in either basin with aeration and iron addition. Demonstrated results in the north basin and additional data collection should precede large-scale application in the south or west basin, but eventually some form of aeration system is likely to be needed in each basin.

On a smaller scale, use of diffusion aeration and phosphorus inactivators (aluminum or iron) or substrates to promote biological treatment could be used to mitigate inputs from Lake Sunowo to the north basin and from the Elk River to the south basin. The cost associated with such a system for the Elk River suggests that more monitoring data should be gathered before making such an investment. The cost of a pilot project using iron for Lake Sunowo water entering the north basin would cost about $11,000 for a five-month period and is consistent with the internal recycling controls already recommended.

Alternatively, installation of a small aeration unit and a series of “bioplates” at the northern end of the north basin should accomplish the same result at a cost of about $20,000. If successful, the summer load to the north basin would approach the permissible limit, providing superior clarity and fish habitat during the period of most intense use. Either the iron addition or the aeration/bioplate approach is recommended in association with the aeration program and monitoring for the north basin, with the bioplates favored in this pilot test, if affordable. The capital cost for the use of biological treatment substrates is greater than that for iron addition in this case, but the operational costs of the substrates are less over the long term. Additional detail is provided in Annex D.

Assuming that inputs from the Elk River are significant and pilot-testing at the Lake Sunowo inlet to the north basin of Lake Elckie is successful, aeration systems with iron or aluminum injection capability and/or bioplates should be considered for the Elk River inlet to the south basin. Controlling inputs to the Elk River is preferable, but this is a long process in reality and removal at the point of input to the lake could provide interim relief. An approximate capital cost of $40,000 is expected, with operational expenses linked to iron supply and aeration for iron addition and to aeration only for the bioplates.

B. Secondary Management Actions

Shoreline stabilization. The areas needing shoreline stabilization are not extensive, but should be addressed as time and funds warrant. Some areas could be handled as local service projects, while others may require engineering support and more expensive materials. Opportunities to handle problem areas should be looked for as they arise.

Swimming area management. Placement of 0.5 m of clean sand over the bottom and woody debris in the swimming area could markedly improve swimming conditions and may decrease color in the water. In this case, this approach is technically and economically more feasible than dredging.

Using a string of bioplates to sequester this cove and then aerating in a way that would reduce algal density and improve the swimming area may also be possible. Although the exact level of interaction between the swimming cove and the remainder of the lake is not now clearly understood, it would be desirable to have a test case for this approach (the north basin fish hatchery effluent) before attempting it in the south basin.

Fish stocking program. Stocking to decrease the prey fish-to-predator ratio toward a desirable level of about 6 to 1 is recommended. From the perspective of community stability and fisherman satisfaction, converting prey fish to harvestable predator biomass will improve the fishery. Limits should be placed on the harvest of predator species to allow specimens to reach reproductive age plus two years. The goal could be a stocking level of 250 fingerling or larger predators per hectare. The Polish Fishing Association should be worked with to achieve consensus and compliance.

Submergent vegetation enhancement program. Seeding shallow areas with submergent vegetation forms desirable for the lake should be considered. Establishment of pondweeds of the genus *Potamogeton* would be especially appropriate in this lake. No action is warranted, however, until water clarity is improved.

Lake clean-up and festival. An annual clean-up day could be initiated for peripheral trash and debris, with a transition into a lake festival combining environmental education with water- oriented fun activities such as boat races and fishing derbies. Setting the festival in late spring would get the lake periphery clean before summer, generating enthusiasm for the lake at the start of its most intensive use.

C. Management Timeline

There is already a timeline developed as part of the Environmental Protection Action Plan (Annex C), but the nature of in-lake management actions was expected to change as a result of this investigation. Improvements to the sanitary and storm water drainage systems are proceeding generally in line with the plan, and further actions will be delayed only where funding becomes a problem. Most other land-based management actions are in a similar situation.

The following timeline is envisioned for in-lake management actions:

June 1997	Begin monitoring program (continues through August 1998).
June 1997-?	Funding efforts proceed.
September 1997	Issue bid package for aeration system for north basin and pilot phosphorus inactivation for inflow from Lake Sunowo.
November-May 1998	Install aeration system and pilot phosphorus inactivation system.
June-September 1998	Evaluate in-lake program results.
October 1998-?	Plan next phase of in-lake improvements, focusing on south and west basins.

Obviously, the actions taken and the timeline for each are as much a function of funding as any other factor, but the above schedule represents a realistic implementation time frame for the next phase of in-lake improvements. Since funding of this program represents a major investment, cost-sharing arrangements with any interested agency or party should be sought at the earliest possible time.

Securing some funding through EAPS to prepare the bid documents for the in-lake management actions proposed for the north basin may be possible. While EAPS is unlikely to participate in funding the implementation, it could cost-share with the town or other agency to prepare conceptual and detailed engineering drawings for the restoration work. Minimizing the design phase may be possible if the town is willing to evaluate potentially widely varying proposals for accomplishing the stated goals. More detailed plans and specifications would be needed, however, if the town desires to have multiple firms bid on a distinct system in an easily comparable format. An outline of goals, performance criteria, and applicable specifications for proposed work on the north basin of Lake Elckie is included in Annex D.

ANNEX A
REFERENCES

Babin, J., E. Prepas, T. Murphy and H. Hamilton 1989. A test of the effects of lime on algal biomass and total phosphorus concentrations in Edmonton stormwater retention lakes. *Lake and Reservoir Management* 5:129-135.

Barko, J., W.F. James, W.D. Taylor and D.G. McFarland 1990. Effects of alum treatment on phosphorus and phytoplankton dynamics in Eau Galle Reservoir: A synopsis. *Lake and Reservoir Management* 6:1-8.

Barroin, G. 1980. Sediment treatment for phosphorus inactivation. Restoration of Lakes and Inland Waters. EPA 440/5-81-010 USEPA, Washington, D.C.

Connor, J. 1992. Personal communication.

Connor, J. and M. Martin 1989a. An assessment of sediment phosphorus inactivation, Kezar Lake, New Hampshire. *Water Resources Bulletin* 25:845-853.

Connor, J. and G. Smith 1986. An efficient method of applying aluminum salts for sediment phosphorus inactivation in lakes. *Water Resources Bulletin* 22:661-664.

Cooke, G.D., E.B. Welch, S.A. Peterson and P.A. Newroth 1993. Lake and Reservoir Restoration. Lewis Publishers, Boca Raton, Florida.

Davison, W., G.W. Grime and C. Woof 1992. Characterization of lacustrine iron sulfide particles with proton induced X-ray emission. *Limnol. Oceanogr.* 37:1770-1776.

EAPS 1997. File information relating to Lake Elckie. Warsaw, Poland.

EcoFund 1996. Program brochure, provided by Ireneusz Mirowski, project manager.

General Environmental Systems 1993. Products and Services Brochure. GES, Oak Ridge, North Carolina.

Gromadzki, J. 1996. Offer and design concept for Lake Elckie reclamation. EkoTech, Warsaw, Poland.

Gromadzki, J. 1997. Unpublished data for several Polish lakes. Warsaw, Poland.

Harper, H. 1992. Personal communication with an engineer involved in phosphorus inactivation.

Jones, J. and R. Bachmann. 1976. Prediction of phosphorus and chlorophyll levels in lakes. *Journal of the Water Pollution Control Federation* 48:2176-2184.

Kirchner, W. and P. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lakes. *Water Resources Res.*11:182-183.

Kortmann, R., M.E. Conners, G.W. Knoecklein and C.H. Bonnell 1988. Utility of layer aeration for reservoir and lake management. *Lake and Reservoir Management* 4:35-50.

Kudelska, D. 1992. Approaches to urban lakes assessment and restoration in Poland. *Water Pollution Research Journal Canada* 27:287-300.

Kufel, L. 1996. Trophic and Water Quality Parameters, Lake Elckie. Polish Academy of Sciences, Institute of Ecology, Hydro Biological Station, Mikolajki, Poland.

Larsen, D. and H. Mercier. 1976. Phosphorus retention capacity of lakes. *J. Fish. Res. Bd. Can.* 33:1742-1750.

LEAPS 1996. Environmental Protection Action Plan. Elk, Poland.

LEAPS 1997. Implementation Plan of Environmental Protection Action Plan. Elk, Poland.

Matson, T. 1993. Aerating ponds. *Country Journal*, May/June 1993.

McQueen, D.J., D.R.S. Lean and M.N. Charlton 1986. The effects of hypolimnetic aeration on iron-phosphorus interactions. *Water Research* 20:1129-1135.

Monagle, W. 1992. Personal communication.

Murphy, T., K. Hall and T. Northcote 1988. Lime treatment of a hardwater lake to reduce eutrophication. *Lake and Reservoir Management* 4:51-62.

Nurnberg, G. 1984. The prediction of internal phosphorus load in lakes with anoxic hypolimnia. *Limnol. Oceanogr*. 29:111-124.

Olem, H. and G. Flock (editors) 1990. The Lake and Reservoir Restoration Guidance Manual. Second Edition. EPA-440/4-90-006, U.S. Environmental Protection Agency, Washington, D.C.

Payne, F.E., C.R. Laurin, K. Thornton and G. Saul 1991. A strategy for evaluating in-lake treatment effectiveness and longevity. NALMS, Alachua, Florida.

Polish Fishing Society 1994. Data from Lake Elckie study. Gizycko, Poland.

Smeltzer, E. 1990. A successful alum/aluminate treatment of Lake Morey, Vermont. *Lake and Reservoir Management* 6:9-19.

Smeltzer, E. 1993. Personal communication.

Stauffer, R. 1981. Simple strategies for estimating the magnitude and importance of internal phosphorus supplies in lakes. 600/3-81-015, U.S. Environmental Protection Agency, Corvallis, Oregon.

Tyning, P. 1992. Personal communication.

Vollenweider, R. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Technical Report to OECD, Paris, France.

Vollenweider, R. 1975. Input-output models with special reference to phosphorus loading concept in limnology. *Schweiz. Z. Hydrol.* 37:53-62.

Walker, W., C.E. Westerberg, D.J. Schuler and J.A. Bode 1989. Design and evaluation of eutrophication control measures for the St. Paul water supply. *Lake and Reservoir Management* 5:71-83.

Wasilewski, J. 1997. Data from the files of the Town of Elk. LEAP coordinator, Elk, Poland.

Welch, E.B., C.L. DeGasperi, D.E. Spyridakis and T.J. Belnick 1988. Internal phosphorus loading and alum effectiveness in shallow lakes. *Lake and Reservoir Management* 4:27-33.

Willenbring, P., M. Miller and W. Weidenbacher 1984. Reducing sediment phosphorus release rates in Long Pond through the use of calcium nitrate. EPA 440/5-84-001, U.S. Environmental Protection Agency, Washington, D.C.

ANNEX B
CALCULATIONS

Hydrologic Estimates

Basin (all values in m^3/yr)

Source	North	South	West
Precipitation (@ 0.635m/yr)	511,000	1,178,000	740,000
Ground water (@ 10% of lake area x 10 l/m^2/sec)	587,000	1,354,000	850,000
Direct runoff (@ area x precipitation x runoff coeff.) Urban Agriculture	 318,000 76,000	 953,000 -	 - 229,000
Tributaries (from data or area yield) Elk R. L. Sunowa Hatchery Szyba Szarek	 - 14,507,000 7,569,000 -	 119,206,000 - - 158,000 -	 - - - - 1,577,000
Flow from other basins	-	23,568,000	146,417,000
Total (m^3/yr) (m^3/sec)	23,568,000 0.75	146,417,000 4.64	149,813,000 4.76
Lake area (ha)	80.4	185.5	116.5
Lake mean depth (m)	9.7	24.2	4.1
Lake volume (m^3)	7,779,000 7,798,800	44,885,000 44,891,000	4,756,000 4,776,500
Detention time (days)	120	112	12
Flushing rate (#/yr)	3.0	3.3	31.5

Note: Evaporation/groundwater losses will reduce actual flow from north basin → south basin and south basin → west basin, but only slightly.

Estimated Dissolved Oxygen Deficit

No detailed information exists for the temporal progression of stratification in Lake Elckie, but it appears typical of deep temperate zone lakes—stratification begins in June and is very strong by August.

Assume that the lake is stratified sufficiently by June 15 to prevent oxygen transport to the hypolimnion. We know from August T-DO profiles that there is no oxygen in the hypolimnion by early August below 5 m in the north basin, no oxygen below 36 m and very little oxygen between 7 and 36 m in the south basin, and no oxygen below 5 to 6 m in the west basin. Note also that there is an anoxic layer right at the thermocline in the south basin, but this is due to decomposition of organic particles trapped by the density gradient, not sediment oxygen demand. Note also that the west basin is minimally stratified due to shallow depth—any estimate of DO deficit there would probably be substantially underestimated on a mass-balance basis, due to unaccounted inputs of atmospheric oxygen.

North Basin				O_2 Lost	
Depth (m)	O_2 (mg/l)	% of Volume	Volume (m^3)	(mg/l)	(mg total)
0-5	11.0	79	6,145,000	0.0	0
5-24	0.0	21	1,634,000	11.0	17,974,000,000

∴ 17,974,000,000 mg O_2 lost from 1,634,000,000 l over 42 days (or faster)
(= 11mg/l for whole hypolimion volume) = 0.26 mg/l/d
On areal basis, have 56 ha of hypolimnion area ⇒ 764 mg/m^2/d
On daily total volume basis ⇒ 428 kg/d

South Basin				O_2 Lost	
Depth (m)	O_2 (mg/l)	% of Volume	Volume (m^3)	(mg/l)	(mg total)
0-8	11.0	40.6	18,200,000	0	0
8-10	0	8.4	3,800,000	11	41,800,000,000*
10-20	2.5	22.1	9,900,000	8.5	84,150,000,000
20-36	2.0	18.9	8,500,000	9.0	76,500,000,000
36-57	0	10	4,500,000	11	49,500,000,000
Total		100	44,900,000		210,150,000,000

* Excluded from SOD total.

∴ 210,150,000,000 mg O_2 lost from 22,900,000,000 l over 42 days (or faster)
(= 8.5 mg/l from 10-20 m, 9mg/l from 20-36m, 11 mg/l from 36-57 m) = 0.22 mg/l/d
On areal basis, have approximately 170 ha of hypolimnion area ⇒ 2,943 mg/m^2/d
On daily total volume basis ⇒ 5,004 kg/d

West basin. Assumed to have similar volumetric O_2 loss (0.22 - 0.26 mg/l/d) but partly offset by inputs.

Estimated Phosphorus Release from Sediment

No detailed information on vertical distribution of phosphorus or the temporal progression of its release from sediments is available, but phosphorus is likely to be released as O_2 is depleted and thereafter, providing no special inactivators are present (e.g. aluminum, very high calcium).

Estimation by difference between epilimnetic and hypolimnetic concentration of dissolved phosphorus multiplied by volume of anoxic layer and divided by time period of expected release. Assume T = 42d for initial calculation of daily release, but extend to 90 d for summer loading estimate. Dissolved phosphorus used to avoid influence of accumulated particles.

North basin:
P_{epi} ≈0.03 (possibly less as background can be as high as 0.05) mg/l
P_{hypo} ≈0.35 (range of 0.286-0.402) mg/l
Anoxic layer = 1,634,000 m^3 (entire hypolimnion) or 560,000 m^2

∴ 1,634,000 m^3 x 1,000 l/m^3 x (0.35-0.03 mg/l) divided by 42 d =12,450,000 mg/d
=12.5 kg/d
12.5 kg/d ⇒ 12,450,000 mg/d over 560,000 m^2 =22.2 mg/m^2/d
12.5 kg/d for 90 days (continued summer release) =1,125 kg/summer

South basin:
P_{epi} ≈0.03 (often higher from external inputs) mg/l
P_{hypo} ≈0.20 (range of 0.130-0.343) mg/l
Anoxic layer = 4,500,000 m^3 (deep zone) to 22,400,000 m^3 (>10m depth)
(Note: probable P gradient—use avg. of min. and max. vol. as estimate)

∴ 13,450,000 m^3 x 1,000 l/m^3 x (0.20-0.03 mg/l) divided by 42 d = 54,440,000 mg/d
= 54.4 kg/d
54,440,000 mg/d over 1,700,000 m^2 = 32 mg/m^2/d
(range = 10.7-53.3 mg/m^2/d
54.4 kg/d for 90 days = 4,896 kg/summer
(range = 1,600-8,100 kg/summer

West basin:
More difficult due to greater mixing and P flux
Assume P_{epi} ≈ 0.03 (as background level) mg/l
P_{hypo} ≈ 0.50 (range of 0.318 to 0.647) mg/l
Anoxic layer = 62,000 m^3
(Note: probable loss of P to mixing—estimate is a minimum)

∴ 62,000,000 l x (0.50-0.03 mg/l) divided by 42 d = 694,000 mg/d
= 0.7 kg/d
694,000 mg/d over 150,000 m^2 = 4.6 mg/m^2/d
0.7 kg/d over 90 days = 63 kg/summer

This reflects only accumulation in small hypolimnion—need estimate over larger lake area.

Alternative West Basin Internal Load Calculations

From south basin - 4,494,000 g in 149,813,000 m^3 @ 0.03 mg/l
From other sources - 306,000 g in 3,396,000 m^3 @ 0.09 mg/l

Final Conc. Avg ≈ 0.130 mg/l

∴ Internal load causes difference between 0.130 and weighted mean of above, = 0.130-0.031 = 0.099 mg/l in 153,206,000 m^3 = 15,121 kg/yr

If assume even release over year ⇒
15,121 kg/1,165,000 m^3 = 13,000 mg/m^3/yr = 35.6 mg/m ^{2}/d

Another alternative:

Assume west basin sediment P release = south basin release = 32 mg/m^2/d
For 90 day summer period ⇒ 32 mg/m^2/d x 1,165,000 m^2 x 90 = 3,355 kg/summer

Either of the two alternatives above are possible, based on low O_2 @ bottom and apparently limited Fe level. First estimate of 63 kg reflects only hypolimnion volume and is not relevant to recycle in whole lake under apparent conditions.

External Load Estimates

Former sanitary sewage discharge to south basin:
Assume 20,000 m^3/d @ 4-6 g/m^3 = 80-120 kg/d = 29,200-43,800 kg/yr

Current sanitary sewage discharge to north and south basins:
Assume 10% of town, 5% to each basin
~ 2,800 people @ 1.5 kg/person/yr to septic system
Assume 1-5% of septic P reaches lake ⇒ 42-210 kg/yr/bas.

Direct urban runoff:
North basin - Approx. 100 ha drainage @ 0.5-1.0 kg/ha/yr = 50-100 kg/yr
or 100 ha x 0.635 m precip. x 0.5 runoff coeff. x 0.25 g/m^3 = 79 kg/yr

South basin - Approx. 300 ha drainage @ 0.5-1.0 kg/ha/yr = 150-300 kg/yr
or 300 ha x 0.635 m precip. x 0.5 runoff coeff. x 0.25 g/m^3 = 238 kg/yr

West basin - No known direct urban drainage

Indirect urban runoff to Elk R. and south basin in Elk:
Approx. 2,000 ha drainage @ 0.5-1.0 kg/ha/yr = 1,000-2,000 kg/yr
or 2,000 ha x 0.635 m precip. x 0.5 runoff coeff. x 0.25 g/m^3 = 1,588 kg/yr
Would expect some attenuation of load in river

Total inputs from Elk R. to south basin (whole Elk R. drainage):
@ approx. 3.78 m^3/sec (avg. flow) x ~0.4 mg/l (avg. obs. P level) = 47,700 kg/yr
@ approx. 2.02 m^3/sec ("low" avg. flow) x 0.2 mg/l (min. est. P level) = 12,700 kg/yr
This includes runoff from town of Elk + upstream inputs

Direct agricultural load:
Farm to north basin @ ~ 40 ha @ 0.2-0.6 kg/ha/yr = 8-24 kg/yr
(This farm appears to have excellent management practices.)
Fish hatchery to north basin @ 0.24 m^3/sec x (0.04-0.37) mg/l = 303-2,800 kg/yr

@ expected avg. = 0.08 mg/l = 600 kg/yr

Farms to west basin—some crop land plowed perpendicular to hillside, much manure storage/spreading, but usually with substantial buffer. Assume 300 ha @ 1 kg/ha = 300 kg/yr. (Note: cows in lake @ west end, plus intense manure spreading up gradient of L. Szarek which flows to west basin)

Load from L. Sunowa to north basin:

Approx. avg. of 480 l/sec @ 0.1-0.2 mg/l = 1,450-2,900 kg
(Note: high iron may inactivate much P; also flow skewed to spring)

Phosphorus Model Results

Mass-balance model = obs. P conc. x volume x flushing rate; it is the minimum load necessary to create obs. P conc.

Other models are based on mass balance with additional terms to account for phosphorus loss to sediment or recycling; they calculate the “effective” load necessary to produce obs. P conc. under existing hydrologic conditions.

Basin	Units	Mass-Balance	Model Range	Model Average	Permissibl e Level	Critical Level	Predicted SDT (m)
North	$g/m^2/yr$ kg/yr	0.88 707	0.97-1.38 777-1,113	1.19 953	0.54 436	1.08 871	1.85
South	$g/m^2/yr$ kg/yr	2.37 4,393	2.48-3.68 4,574-6,825	3.04 5,538	0.89 1,652	1.78 3,304	1.91
West	$g/m^2/yr$ kg/yr	16.72 19,476	17.06-20.31 19,878-23,664	18.71 21,791	1.14 1,325	2.28 2,651	0.58

ANNEX D
TERMS OF REFERENCE FOR NORTH BASIN RESTORATION

A. Aeration System

Goals

- Eliminate hydrogen sulfide production in the north basin.
- Reduce phosphorus release from the sediments by 90 percent.
- Maintain adequate oxygen to minimize pathogen survival and provide a summertime coldwater fish refuge.

Desired performance criteria

- Provide a minimum dissolved oxygen level of 1 mg/l throughout the hypolimnion of the north basin at all times.
- Achieve a dissolved oxygen concentration of 5 mg/l in at least 50 percent of the hypolimnion of the north basin between June and October.
- Do not destratify the north basin during summer.

Specifications to meet goals and performance criteria

- Capacity to deliver at least 400 kg of oxygen per day on a continuous basis.
- Capacity to increase input to 800 kg per day without additional capital cost.
- Ability to add oxygen without destratifying the lake during the summer.
- Achieve distribution of oxygen to provide a minimum of 1 mg/l at sediment-water interface.
- Achieve measurable improvement during the first summer of operation.

B. Chemical Phosphorus Inactivation System

Goals

- Supplement aeration system in the event of inadequate ambient levels of phosphorus inactivators.
- Reduce summer transport of phosphorus to the north basin epilimnion by 90 percent.
- Reduce availability of summer inputs to the north basin from Lake Sunowo and the fish hatchery by 50 percent.

Desired Performance Criteria

- Achieve a ratio of phosphorus inactivator to phosphorus (Fe:P or Al:P) of 10:1.
- Allow increase in ratio to 20:1 with no additional capital cost.
- Deliver inactivator under well-mixed conditions to enhance reaction efficiency.
- Avoid pH depression below a value of 6.0.

Specifications to meet goals and performance criteria

- Capacity to deliver 11,000 kg of inactivator to the hypolimnion during the summer.
- Capacity to increase hypolimnetic delivery to 22,000 kg without additional capital cost.
- Capacity to deliver 1,000 kg of inactivator to the inflows from Lake Sunowo during the summer, or to make this addition in the extreme northern end of the north basin, if not addressed by biological inactivation (see below).
- Capacity to add buffering solution in the event of adverse pH fluctuation.
- Ability to ensure complete mixing and reaction efficiency of 10 percent.

C. Biological Phosphorus Inactivation System

Goals

- Reduce availability of summer inputs to the north basin from Lake Sunowo and the fish hatchery by 50 percent.

Desired performance criteria

- Establish active uptake of phosphorus on artificial, suspended substrates.
- Deploy adequate substrate area to effectively treat inflows from Lake Sunowo and the fish hatchery.

Specifications to meet goals and performance criteria

- Install 300 bio-hydro plates (product of EkoTech) or functional equivalent in a semi-circle around inflow area from Lake Sunowo and the fish hatchery.
- Provide all structures, floats, weights, and lines necessary to deployment.
- Maintain plates or functional equivalent as necessary through the summer season.

D. Monitoring Program for Aeration and Inactivation

Goals

- Assess the performance of in-lake management methods in the maintenance of oxygen levels and reduction of phosphorus availability in the north basin.

Desired performance criteria

- Document the concentration of oxygen over a meaningful portion of the north basin.
- Document the concentration of phosphorus over a meaningful portion of the north basin.

Specifications to meet goals and performance criteria

- Establish a sampling grid over the surface of the north basin, delineated on a map as a set of criss-crossing perpendicular lines, with each intersection 200 m from adjacent intersections (i.e., create a lattice of 200 m by 200 m blocks). For the north basin, this should result in 20 sampling points at least 100 m from shore.

- Denote locations of intersections with buoys or use a global positioning system to locate points.

- Generate temperature and oxygen profiles at 2 m vertical intervals at each intersection at least once every two weeks (more frequently if warranted by the rate of change) between May and September, and monthly from October through April.

- Collect and analyze samples for total and dissolved phosphorus 1 m under the surface, near the top of the metalimnion, and 1 m off the bottom at every other intersection (10 locations) once per month from May through September, once in December and once in March or April (immediately after winter ice disappears).

- Monitor pH at the four closest intersections to any chemical phosphorus inactivator input point on a weekly basis, during any period of inactivator addition, at near-surface, metalimnetic, and near-bottom depths.

- Summarize all data in tabular and graphic form to facilitate comparisons over space and time.

ANNEX E
GENERAL AQUATIC GLOSSARY

Abiotic. Pertaining to any non-biological factor or influence, such as geological or meteorological characteristics.

Acid precipitation. Atmospheric deposition (rain, snow, dryfall) of free or combined acidic ions, especially the nitrates, sulfates, and oxides of nitrogen and sulfur fumes from industrial smoke stacks.

Adsorption. External attachment to particles. The process by which a molecule becomes attached to the surface of particle.

Algae. Aquatic single-celled, colonial, or multi-celled plants, containing chlorophyll and lacking roots, stems, and leaves.

Alkalinity. A reference to the carbonate and bicarbonate concentration in water. Its relative concentration is indicative of the nature of the rocks within a drainage basin. Lakes in sedimentary carbonate rocks are high in dissolved carbonates (hard-water lakes), whereas lakes in granite or igneous rocks are low in dissolved carbonate (soft-water lakes).

Ammonium. A form of nitrogen present in sewage. Generated from the decomposition of organic nitrogen. Can also be formed when nitrites and nitrates are reduced. Ammonium is particularly important since it has high oxygen and chemical demands and is toxic to fish in un-ionized form. It is an important aquatic plant nutrient because it is readily available.

Anadromous. An adjective used to describe types of fish that breed in freshwater rivers but spend most of their adult lives in the ocean. Before breeding, anadromous adult fish ascend the rivers from the sea.

Anoxic. Without oxygen.

Aphotic zone. Dark zone, below the depth to which light penetrates. Generally equated with the zone in which most photosynthetic algae cannot survive, due to light deficiency.

Aquifer. Any geological formation that contains water, especially one that supplies wells and springs; can be a sand and gravel aquifer or a bedrock aquifer.

Artesian. The occurrence of groundwater under sufficient pressure to rise above the upper surface of the aquifer.

Assimilative capacity. Ability to incorporate inputs into the system. With lakes, the ability to absorb nutrients or other potential pollutants without showing extremely averse effects.

Attenuation. The process whereby the magnitude of an event is reduced, as the reduction and spreading out of the impact of storm effects or the removal of certain contamination as water moves through soil.

Background value. Value for a parameter that represents the conditions in a system before a given influence in space or time.

Bathymetry. The measurement of depths of water in oceans, seas, or lakes or the information derived from such measurements.

Benthic deposits. Bottom accumulations that may contain bottom-dwelling organisms and/or contaminants in a lake, harbor, or stream bed.

Benthos. Bottom-dwelling organisms living on, within, or attached to the sediment. The phytobenthos includes the aquatic macrophytes and bottom-dwelling algae. The zoobenthos (benthic fauna) includes a variety of invertebrate animals, particularly larval forms and mollusks.

Best management practices. State-of-the-art techniques and procedures used in an operation such as farming or waste disposal to minimize pollution or waste.

Biological oxygen demand (BOD). An indirect measure of the organic content of water. Water high in organic content will consume more oxygen due to the decomposition activity of bacteria in the water than water low in organic content. It is routinely measured for wastewater effluents. Oxygen consumption is proportional to the organic matter in the sample.

Biota. Plant (flora) and animal (fauna) life.

Biotic. Pertaining to biological factors or influences, concerning biological activity.

Bloom. Excessively large standing crop of algae, usually visible to the naked eye.

Bulk sediment analysis. Analysis of soil material or surface deposits to determine the size and relative amounts of particles composing the material.

CFS. Cubic feet per second, a measure of flow.

Chlorophyll. Major light gathering pigment of all photosynthetic organisms imparting the characteristic color or green plants. Its relative measurement in natural waters is indicative of the concentration of algae in the water.

Chlorophyte. Green algae, algae of the division *Chlorophyta.*

Chrysophyte. Golden or yellow-green algae, algae of the division *Chrysophyta.*

Coliforms. Generally refers to bacterial species normally present in the large intestine (colon) and feces of all warm-blooded animals.

Color. Color is determined by visual comparison of a sample with known concentrations of colored solutions and is expressed in standard units of color. Certain waste discharges may turn water to colors that cannot be defined by this method; in such cases, the color is expressed qualitatively rather than numerically. Color in lake waters is related to solids, including algal cell concentration and dissolved substances.

Combined sewer. A sewer intended to serve as both a sanitary sewer and a storm sewer. It receives both sewage and surface runoff.

Composite sample. A number of individual samples collected over time or space and composited into one representative sample.

Concentration. The quantity of a given constituent in a unit of volume or weight of water.

Conductivity. The measure of the total ionic concentration of water. Water with high total dissolved solids (TDS) level would have a high conductance. A conductivity meter tests the flow of electrons through the water which is heightened in the presence of electrolytes (TDS).

Confluence. Meeting point of two rivers or streams.

Conservative substance. Non-interacting substance, undergoing no kinetic reaction; chlorides and sodium are approximate examples.

Cosmetic. Acting upon symptoms or given conditions without correcting the actual cause of the symptoms or conditions.

Cryptophyte. Algae of variable pigment concentrations, with various other unusual features. Algae of the division *Cryptophyta*, which if often placed under other taxonomic divisions.

Cyanophyte. Bluegreen algae, algae of the division *Cyanophyta*, actually a set of pigmented bacteria.

Decomposition. The metabolic breakdown of organic matter, releasing energy and simple organic and inorganic compounds that may be utilized by the decomposers themselves (the bacteria and fungi).

Deoxygenation. Depletion of oxygen in an area, used often to describe possible hypolimnetic conditions, leading to anoxia.

Diatom. Specific type of chrysophyte, having a siliceous frustule (shell) and often elaborate ornamentation, commonly found in great variety in fresh or saltwaters. Often placed in its own division, the *Bacillariophyta.*

Dinoflagellate. Unicellular algae, usually motile, having pigments similar to diatoms and certain unique features. More commonly found in saltwater. Algae of the division *Pyrrhophyta.*

Discharge measurement. The volume of water passing a given location in a given period, usually measured in cubic feet per second (ft^3/s) or cubic meters per minute (m^3/min).

Dissolved oxygen (DO). Refers to the uncombined oxygen in water available to aquatic life. Temperature affects the amount of oxygen that water can contain. Biological activity also controls the oxygen level. DO levels are generally highest during the afternoon and lowest just before sunrise.

Diurnal. Varying over the day, from day time to night.

Domestic wastewater. Water and dissolved or particulate substances after use in any of a variety of household tasks, including sanitary systems and washing operations.

Drainage basin. A geographical area or region that is so sloped and contoured that surface runoff from streams and other natural watercourses are carried away by a single drainage system by gravity to a common outlet. Also referred to as a watershed or drainage area. The definition can also be applied to subsurface flow in groundwater.

Dystrophic. Trophic state of a lake in which large quantities of nutrients may be present, but are generally unavailable (due to organic binding or other causes) for primary production. Often associated with acid bogs.

Ecosystem. A dynamic association or interaction between communities of living organisms and their physical environment. Boundaries are arbitrary and must be stated or implied.

Elutriate. The washings of a sample of material.

Epilimnion. Upper layer of stratified lake. Layer that is mixed by wind and has a higher average temperature than the hypolimnion. Roughly approximates the euphotic zone.

Erosion. The removal of soil from the land surface, typically by runoff water.

Euglenoid. Algae similar to green algae in pigment composition, but with certain unique features related to food storage and cell wall structure. Algae of the division *Euglenophyta.*

Eutrophic. High-nutrient, high-productivity trophic state generally associated with unbalanced ecological conditions and poor water quality.

Eutrophication. Process by which a body of water ages, most often passing from a low-nutrient concentration, low-productivity state to a high-nutrient concentration, high-productivity stage. Eutrophication is a long-term natural process, but it can be greatly accelerated by human activities. Eutrophication as a result of human activities is termed cultural eutrophication.

Fauna. General term referring to all animals.

Fecal coliform bacteria. Bacteria of the coliform group that are present in the intestines or feces of warm-blooded animals. They are often used as indicators of the sanitary quality of the water. In the laboratory, they are defined as all organisms that produce blue colonies within 24 hours when incubated at 44.5^{o}C+0.2^{o}C on M-FC medium (nutrient medium for bacterial growth). Their concentrations are expressed as number of colonies per 100 ml of sample.

Fecal streptococci bacteria. Bacteria of the *Streptococci* group found in intestines of warm-blooded animals. Their presence in water is considered to verify fecal pollution. They are characterized as gram-positive, coccoid bacteria capable of growth in brain-heart infusion broth. In the laboratory, they are defined as all the organisms that produce red or pink colonies within 48 hours at 35^{o}C+1.0^{o}C on KF medium (nutrient medium for bacterial growth). Their concentrations are expressed as number of colonies per 100 ml of sample.

Flora. General term referring to all plants.

Food chain. A linear characterization of energy and chemical flow through organisms such that the biota can be separated into functional units with nutritional interdependence. Can be expanded to a more detailed characterization with multiple linkage, called a food web.

Grain size analysis. A soil or sediment sorting procedure that divides the particles into groups depending on size so that their relative amounts may be determined. Data from grain size analyses are useful in determining the origin of sediments and their behavior in suspension.

Groundwater. Water in the soil or underlying strata, subsurface water.

Hardness. A physical-chemical characteristic of water that is commonly recognized by the increased quantity of soap required to produce lather. It is attributable to the presence of alkaline substances (principally calcium and magnesium) and is expressed as equivalent calcium carbonate ($CaCO_3$).

Humus. Humic substances form much of the organic matter of sediments and water. They consist of amorphous brown or black-colored organic complexes.

Hydraulic detention time. Lake water retention time. Amount of time that a random water molecule spends in a water body. Time that it takes for water to pass from an inlet to an outlet of a water body.

Hydraulic dredging. Process of sediment removal using a floating dredge to draw mud or saturated sand through a pipe to be deposited elsewhere.

Hydrologic cycle. The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

Hypolimnion. Lower layer of a stratified lake. Layer that is mainly without light, generally equated with the aphotic zone, and has a lower average temperature than the epilimnion.

Impervious. Not permitting penetration or percolation of water.

Intermittent. Non-continuous, generally referring to the occasional flow through a set drainage path. Flow of a discontinuous nature.

Kjeldahl nitrogen. The total amount of organic nitrogen and ammonia in a sample, as determined by the Kjeldahl method, which involves digesting the sample with sulfuric acid, transforming the nitrogen into ammonia, and measuring it.

Leachate. Water and dissolved or particulate substances moving out of a specified area, usually a landfill, by a completely or partially subsurface route.

Leaching. Process whereby nutrients and other substances are removed from matter (usually soil or vegetation) by water. Most often this is a chemical replacement action, prompted by the water's qualities.

Lentic. Standing, having low net directional motion. Refers to lakes and impoundments.

Limiting nutrient. That nutrient of which there is the least quantity, in relation to its importance to plants. The limiting nutrient will be the first essential compound to disappear from a productivity system and will cause cessation of productivity at that time. The chemical form in which the nutrient occurs and the nutritional requirements of the plants involved are important here.

Limnology. The comprehensive study of lakes, encompassing physical, chemical, and biological lake conditions.

Littoral zone. Shallow zone occurring at the edge of aquatic ecosystems, extending from the shoreline outward to a point where rooted aquatic plants are no longer found.

Loading. Inputs into a receiving water that may exert a detrimental effect on some subsequent use of that water.

Lotic. Flowing, moving. Refers to streams or rivers.

Macrofauna. A general term that refers to animals that can be seen with the naked eye.

Macrophyte. Higher plant, macroscopic plant, plant of higher taxonomic position than algae, usually a vascular plant. Aquatic macrophytes are those macrophytes that live completely or partially in water. May also include algal mats under some definitions.

Mesotrophic. An intermediate trophic state, with variable but moderate nutrient concentrations and productivity.

MGD. Million gallons per day, a measure of flow.

Micrograms per liter (μg/1). A unit expressing the concentration of chemical constituents in a solution as mass (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter.

Nitrate. A form of nitrogen that is important since it is the end product in the aerobic decomposition of nitrogenous matter. Nitrogen in this form is stable and readily available to plants.

Nitrite. A form of nitrogen that is the oxidation product of ammonia. It has a fairly low oxygen demand and is rapidly converted to nitrate. The presence of nitrite nitrogen usually indicates that active decomposition is taking place (i.e., fresh contamination).

Nitrogen. A macronutrient that occurs in the forms of organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. Form of nitrogen is related to a successive decomposition reaction, each dependent on the preceding one, and the progress and decomposition can be determined in terms of the relative amounts of these four forms of nitrogen.

Nitrogen-fixation. The process by which certain bacteria and bluegreen algae make organic nitrogen compounds (initially $NH4^+$) from elemental nitrogen (N_2) taken from the atmosphere or dissolved in the water.

Non-point source. A diffuse source of loading, possibly localized but not distinctly definable in terms of location. Includes runoff from all land types.

Nutrients. Compounds that act as fertilizers for aquatic organisms. Small amounts are necessary to the ecological balance of a waterbody, but excessive amounts can upset the balance by causing excessive growths of algae and other aquatic plants. Sewage discharged to a waterbody usually contains large amounts of carbon, nitrogen, and phosphorus. The concentration of carbonaceous matter is reflected in the BOD test. Additional tests are run to determine the concentrations of nitrogen and phosphorus. Storm water runoff often contributes substantial nutrient loadings to receiving waters.

Oligotrophic. Low nutrient concentration, low productivity trophic state, often associated with very good water quality, but not necessarily the most desirable stage, since often only minimal aquatic life can be supported.

Organic. Containing a substantial percentage of carbon derived from previously living organisms; of a living organism.

Overturn. The vertical mixing of layers of water in the spring and fall caused by seasonal changes in temperature in temperate climate zones.

Oxygen deficit. A situation in lakes where respiratory demands for oxygen become greater than its production via photosynthesis or its input from the drainage basins, leading to a decline in oxygen content.

Periphyton. Attached forms of plants and animals, growing on a substrate.

pH. A hydrogen concentration scale from 0 (acidic) to 14 (basic) used to characterize water solutions. Pure water is neutral at pH 7.0.

Phosphorus. A macronutrient that appears in waterbodies in combined forms known as ortho- and poly-phosphates and organic phosphorus. Phosphorus may enter a waterbody in agricultural runoff where fertilizers are used. Storm water runoff from highly urbanized areas, septic system leachate, and lake bottom sediments also contribute phosphorus. A critical plant nutrient which is often targeted for control in eutrophication prevention plans.

Photic zone. Illuminated zone, surface to depth beyond which light no longer penetrates. Generally equated with the zone in which photosynthetic algae can survive and grow, due to adequate light supply.

Photosynthesis. Process by which primary producers make organic molecules (generally glucose) from inorganic ingredients, using light as an energy source. Oxygen is evolved by the process as a byproduct.

Phytoplankton. Algae suspended, floating or moving only slightly under their own power in the water column. Often the dominant algae form in standing waters.

Plankton. The community of suspended, floating, or weakly swimming organisms that live in the open water of lakes and rivers.

Point source. A specific source of loading, accurately definable in terms of location. Includes effluents or channeled discharges that enter natural waters at a specific point.

Pollution. Undesirable alteration of the physical, chemical, or biological properties of water. Addition of any substance into water by human activity that adversely affects its quality. Prevalent examples are thermal, heavy metal, and nutrient pollution.

Potable. Usable for drinking purposes, fit for human consumption.

Primary productivity (production). Conversion of inorganic matter to organic matter by photosynthesizing organisms. The creation of biomass by plants.

Riffle zone. Stretch of a stream or river along which morphological and flow conditions are such that rough motion of the water surface results. Usually a shallow rocky area with rapid flow and little sediment accumulation.

Riparian. Of, or related to, or bordering a watercourse.

Runoff. Water and its various dissolved substances or particulates that flow at or near the surface of land in an unchanneled path toward channeled and usually recognized waterways (such as a stream or river).

Secchi disk transparency. An approximate evaluation of the transparency of water to light. It is the point at which a black and white disk lowered into the water is no longer visible.

Secondary productivity. The growth and reproduction (creation of biomass) by herbivorous (plant-eating) organisms. The second level of the trophic system.

Sedimentation. The process of settling and deposition of suspended matter carried by water, sewage, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material.

Sewage (wastewater). The waterborne, human and animal wastes from residences, industrial/commercial establishments, or other places, together with such ground or surface water as may be present.

Specific conductance. Yields a measure of a water sample's capacity to convey an electric current. It is dependent on temperature and the concentration of ionized substances in the water. Distilled water exhibits specific conductance of 0.5 to 2.0 micromhos per centimeter, while natural waters show values from 50 to 500 micromhos per centimeter. In typical New England lakes, specific conductance usually ranges from 100 to 300 micromhos per centimeter. The specific conductance yields a generalized measure of the inorganic dissolved load of the water.

Stagnant. Motionless, having minimal circulation or flow.

Standing crop. Current quantity of organisms, biomass on hand. The amount of live organic matter in a given area at any point in time.

Storm sewer. A pipe or ditch that carries storm water and surface water, street wash, and other wash waters or drainage, but excludes sewage and industrial wastes.

Stratification. Process whereby a lake becomes separated into two relatively distinct layers as the result of temperature and density differences. Further differentiation of the layers usually occurs as the result of chemical and biological processes. In most lakes, seasonal changes in temperature will reverse this process after some time, resulting in the mixing of the two layers.

Substrate. The base of material on which an organism lives, such as cobble, gravel, sand, muck, etc.

Succession. The natural process by which land and vegetation patterns change, proceeding in a direction determined by the forces acting on the system.

Surface water. Refers to lakes, bays, sounds, ponds, reservoirs, springs, rivers, streams, creeks, estuaries, marshes, inlets, canals, oceans, and all other natural or artificial, inland or coastal, fresh or salt, public or private waters at ground level.

Suspended solids. Solids that can be removed by passing the water through a filter. The remaining solids are called dissolved solids. Suspended solids loadings are generally high in stream systems that are actively eroding a watershed. Excessive storm water runoff often results in high suspended solids loads to lakes. Many other pollutants such as phosphorus are often associated with suspended solids loadings.

Taxon (taxa). Any hierarchical division of a recognized classification system, such as a genus or species.

Taxonomy. The division of biology concerned with the classification and naming of organisms. The classification of organisms is based upon a hierarchical scheme beginning with kingdom and progressing to the species level or even lower.

Tertiary productivity. The growth and reproduction (creation of biomass) by organisms that eat herbivorous (plant-eating) organisms. The third level of the trophic system.

Thermocline. Boundary level between the epilimnion and hypolimnion of a stratified lake, variable in thickness, and generally approximating the maximum depth of light penetration and mixing by wind.

Total coliform bacteria. A particular group of bacteria that is used as an indicator of possible sewage pollution. They are characterized as aerobic or facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C. In the laboratory these bacteria are defined as the organisms that produce colonies within 24 hours when incubated at 35°C+ 1.0°C on M-Endo medium (nutrient medium for bacterial growth). Their concentrations are expressed as number of colonies per 100 ml of sample.

Trophic level. The position in the food chain determined by the number of energy transfer steps to that level; 1 = producer; 2 = herbivore; 3, 4, 5 = carnivore.

Trophic state. The stage or condition of an aquatic system, characterized by biological, chemical, and physical parameters.

Turbidity. The measure of the clarity of a water sample. It is expressed in Nephalometric turbidity units that are related to the scattering and absorption of light by the water sample.

Volatile solids. That portion of a sample that can be burned off, consisting of organic matter, including oils and grease.

Water quality. Used to describe the chemical, physical, and biological characteristics of water, usually with respect to its suitability for a particular purpose or use.

Watershed. Drainage basin, the area from which an aquatic system receives water.

Zooplankton. Microscopic animals suspended in the water; protozoa, rotifers, cladocerans, copepods, and other small invertebrates.